DEVELOPMENT OF MINIATURE DIGITAL TELEMETRY SYSTEM

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THESIS

DEVELOPMENT OF MINIATURE DIGITAL TELEMETRY SYSTEM

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This paper describes the design improvements and packaging of a miniature multi-channel digital telemetry system for use in remote controlled aircraft experiments coordinated by the Aeronautical Engineering Department at the Naval Postgraduate School. The avionics package, comprised of data encoder, transmitter, power supply, and pod-mounted sensor package, is small and lightweight; has low current requirement; and can transmit up to nine channels of data. The system has been modified to accept either potentiometric or voltage-output transducers. The ground receiving station provides an analog voltage output for each data channel that is linearly dependent on the airborne sensor output. This thesis emphasizes the modifications made to the existing system to provide more versatility, greater dependability and ease of operation.

TABLE OF CONTENTS

TABLE OF CONTENTS

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I. INTRODUCTION

This paper describes the design improvements of a miniature multi-channel telemetry system developed by Lt. William Gadino at the Naval Postgraduate School. It also describes the development of the buffer equipment required to link the telemetry system with the physical elements to be studied.

A. AIRCRAFT CONSIDERATIONS

For many years it has been recognized that a scale model RPV (Remote Piloted Vehicle) could be a valuable research tool for investigation of aircraft flight characteristics. Today industry is actively involved in correlating data obtained from full size aircraft with similar data obtained from small scale RPVs. When such correlation is fact, tremendous savings will be realized in design and testing of aircraft prior to production, and in research investigation of new ideas and principles. The key to application of RPVs to many purposes, such as law enforcement and Armed Forces training, in addition to aerodynamic research, is a low cost light weight telemetry system for obtaining real time data from the vehicle.

In the general field of RPVs, the aircraft is chosen as the vehicle of investigation because: all types of input data are encountered; size and weight restrictions are most demanding; power requirements must be minimized; and sampling rates are the highest due to maneuverability. In essence,

if the system is compatible with the flight regime, it can be easily adapted to any other environment.

B. TELEMETRY CONSIDERATIONS

A telemetry system was developed by Lt. William Gadino at the Naval Postgraduate School in 1974. [Ref. 1]. The imposed constraints on the designed system were: avionics package size four inches long, two inches wide, and three inches high; maximum power requirements of 250 milliamps; a weight limitation of one half pound; a data sampling rate to exceed one per second; and at least eight separate channels of data to be handled with cross-channel modulation minimized.

C. TELEMETRY SYSTEM MDTS INITIAL CONFIGURATION

Given the task and the constraints, the MDTS (Miniature Digital Telemetry System) was developed. This system was designed around potentiometric (variable resistance) inputs which modulate an RF (radio frequency) carrier to relay the desired information to a ground station. Multiple inputs are handled by a multiplexing (encoding) scheme. At the ground station, the data are decoded and presented on discrete output channels which correspond to the input sensor. The telemetry system is digital, in that the analog input from the transducer (sensor) is linearized and formed into a binary pulse that varies in length depending on the output of the transducer. When received, the pulse is converted into an analog voltage through the decoder and processor circuits.

This section does not deal with the entire MDTS, as many of the components are commercially available units used every day. The components that will not be discussed here are the sensors, transmitter, receiver, and readout devices. What will be discussed are the encoder, multiplexer, decoder, and processor, which were developed exclusively for this application.

1. Encoder

The purpose of the encoder is to: sequentially scan the potentiometric inputs, which can number up to 9; multiplex their values into a data package; and apply them to the transmitter. To identify the data package at the receiver, a synchronization (sync) pulse is provided to separate the end of one package from the beginning of the next.

Referring to Figure 1, the data sent to the transmitter are the output of the 555 timer. This output, a series of pulses, is high when capacitor C is charging, and low when capacitor C is discharging. The length of the low pulses is the intelligence. To ensure that the length of the data pulses varies linearly with respect to the sensor resistance, capacitor C is discharged through a "constant current source." Scanning of the variables is accomplished by sequentially selecting a potentiometer channel and completing a circuit to ground through the 74145 BCD-to-Decimal Decoder/Driver.

For a greater understanding of the encoder, an in-depth description follows. The encoder consists of the following functional components: a Signetics 555 timer,

a Signetics N7490 decade counter, a Signetics N74145 BCD-to-Decimal Decoder/Driver, a National 7432 quadruple 2-input OR gate, and a constant current source.

a. Timer

Coding of information is accomplished using a Signetics 555 timer in the astable operating mode as outlined on Page 6-78 of Ref. 3, with one major difference. Resistor R_B is replaced by the circuit which performs the encoding function as shown in Figure 2. The important concept to keep in mind while working through the circuit is that the output on pin 3 of the 555 timer, shown in Figure 4, is the datum applied to the transmitter.

The astable operation is characterized by the 555 triggering itself and free running as a multivibrator. External timing and sync are not used; the 555 performs the entire operation. Quoting from Ref. 3:

(1) "The external capacitor charges through R_A and R_B and discharges through R_B only. Thus the duty cycle may be precisely set by the ratio of these two resistors." This feature is capitalized on as R_B is replaced by the potentiometric transducer and the constant current source.

(2) "In this mode of operation, the capacitor charges and discharges between 1/3 and 2/3 V_{cc}." The values 1/3 and 2/3 are set internally when the I.C. is manufactured and cannot be changed. When the capacitor reaches 1/3 V_{cc} the charge cycle begins. Pin 7, which leads directly to ground (labeled "discharge"), is open circuited; and V_{cc} is

applied across R_A, diode D1 and the capacitor to ground. When the charge on the capacitor reaches 2/3 V_{cc}, pin 6 (threshold) switches pin 7 to ground. In this application, R_B has been replaced by a diode. When pin 7 is switched, only V_{cc} goes to ground and the capacitor must discharge through the external circuit.

The output of the 555 timer is determined by whether the capacitor is charging or discharging, and the 555 timer responds to these two states. When the capacitor is charging, pin 3 (output) is high. When the capacitor is discharging, pin 3 is low. The time required for the output to change states from low to high or from high to low is 100 nanoseconds. As used here, the time for charging is determined by the value of R_A, and the time to discharge is determined by the resistive value of the potentiometer being evaluated. The applicable formulas are:

Time to charge $T_1 = .693\ R_A\ C$

Time to discharge $T_2 = \dfrac{1/3\ V_{cc}\ C\ R_e\ (R_1 + R_2)}{V_{cc} - .3\ R_1}$

(3) "As in the triggered mode, the charge and discharge times, and therefore the frequency, are independent of the supply voltage V_{cc}." This independency is highly desirable as this particular system will be powered by batteries.

b. Constant Current Source

Capacitors discharge exponentially and a linear output is desired. Linearity can be accomplished by

discharging the capacitor through a constant current source which regulates the rate of discharge. The constant current source, Q1, is shown in Figure 3.

The transistor is biased with voltage divider D2, R_1, and R_2 so that it operates in the active region which is characterized by the collector, base, and emitter currents being constant regardless of the voltage applied. This characteristic is illustrated in Figure 4. The voltage applied by the capacitor to the collector of the transistor does not change the current through the collector and emitter branches. During the discharge from 2/3 to 1/3 V_{cc}, the current through the transistor and load is constant. The value of the resistor (sensor) determines how much current will flow through the transistor, and thereby how much time is required for the capacitor to discharge linearly to the 1/3 V_{cc} point. When the capacitor has discharged, the 555 senses this and applies the voltage again to charge the capacitor. In order to ensure that the capacitor charge time is dependent only on R_A and C, the output through the transistor is open-circuited during the charge cycle.

c. Multiplexer

Up to now the entire system of encoding the information has dealt with only one channel. To make the system earn its way, it should be able to transmit data from more than one input (multiplex), therefore a scanning scheme has been established. The value of the resistor, R_A, between pin 7 of the 555 timer and the supply, V_{cc}, determines the length of time required for the capacitor to charge from

1/3 to 2/3 V_{cc}. This establishes the length of time that the 555 timer output is high and forms a channel separation pulse of fixed length. What will be varied is the time that the 555 output is low. The alternating state of the output can be used for switching as well as for data. By sensing the change of state of the output, the 7490 decade counter counts from Ø to 9 (10 digits), thus designating which channel is determining the length of the data pulse. This is how the serial sequencing, or multiplexing, is accomplished.

The falling output of the 555 timer, caused by the capacitor reaching 2/3 V_{cc}, is sensed by the fall trigger of the Signetics N7490 decade counter. The counter then has an output in BCD (Binary Coded Decimal) at its four output ports. This output will remain until another fall trigger is sensed, at which time it will increment the count by one until all ten channels (9 data and 1 sync) have been sensed, then it goes back to Ø.

The BCD output is applied to the Signetics N74145 BCD-to-Decimal Decoder/Driver, which connects the input corresponding to the BCD number to ground and completes the circuit so the capacitor will discharge. Selection of the output is easily accomplished with this system; however, one other requirement is necessary. All the sensor circuits must be open when the capacitor is charging (as mentioned earlier) to ensure that the charge time is dependent only on the value of R_A and C. Looking at the truth table for the N74145 on Page 2-50 of Ref. 2, it is noted that for any BCD input greater than 10, the circuits will all be open;

therefore, it is desirable to have the number of the sensor being processed less than 10 while the capacitor is discharging, and a number greater than 10 when the capacitor is charging. This is accomplished by placing a National 7432 quadruple OR gate between the 7490 and the 74145. Or-ing the 555 output pulse with the C and D output of the 7490 will produce this result exactly. The multiplexer circuit is shown in Figure 5.

2. Encoder Summary

With the circuits described above, the 9 sensor channels are sequentially scanned. The scanning action through the 9 sensors and the sync produces a multiplexed chain of output pulses. To be compatible with the design of the decoder circuitry, the pulse lengths are chosen as 250 μsec (microseconds) for the fixed spacing pulse, and one to two milliseconds for the variable data pulses which are determined by the sensor values. The sync pulse is set at a value of greater than 2.5 milliseconds. The sequence of pulses discussed is shown in Figure 6 and illustrated in Chart A where the interaction can be appreciated.

As can be seen on Chart 4, the length of time the output of the 555 timer is low is linearly dependent on the value of the resistance in the sensor. Therefore the intelligence, or value of the sensor resistance, is the length of time that elapses between the 250 microsecond pulses.

Based on the times chosen for the pulses and the manufacturer's data on the I.C.s, the time required for the components to change state and thereby affect the accuracy

of the values was calculated. Each of the components changes state in about 100 nanoseconds, which is 0.04% of the time of the shortest (250 μsec.) pulse, consequently, this is not a cource of measurable error.

3. Decoder

The decoder consists of only two I.C.s (as shown in Figure 7), a Fairchild TTμL 9601 retriggerable monostable multivibrator, and a Signetics N8273 10 bit serial-in-parallel out shift register. The purpose of the decoder is to take the pulse train being delivered, through matching circuitry from the receiver, and to sort out the information. The pulse train starts with the 250 microsecond pulse which is generated by the capacitor in the encoder, following selection of the sync channel with its long pulse time. Immediately following the 250 microsecond pulse is data pulse 1, then a 250 microsecond separation pulse followed by data pulse 2, and so on through the sync pulse again.

Implementation is achieved by shifting a 1 (high state) through the 9 output channels of the 8273. The 1 remains in the output channel for the data time corresponding to that channel. The length of time the 1 remains in the channel is the data. The 1 is essentially a constant voltage for the time it resides in the channel. The parallel-out feature of the 8273 is never actually used; the 1 is serially moved through the output registers as shown in Chart B.

Looking at the circuit technically, the 9601 is configured as a "monostable retriggerable multivibrator" as shown on Page 2-47 Ref. 3. The external resistor and

capacitor, which determine the period of the multivibrator, are selected to make the period greater than a data pulse and less than the sync pulse. Hence, as long as the data pulses continue to come in and retrigger the 9601, it remains at its active state with a constant output. The sync pulse, being of longer duration than the multivibrator period, allows the 9601 to relax to its static state. In this application, the $\overline{Q}$ output was chosen, which is 1 during the static state and 0 during the active state. The pulse train is applied to the fall trigger of the 9601 and the resulting output, which is sent to the 8273 is a 1 until the falling edge of the first pulse and then is Ø until the data has been transferred and sufficient time has elapsed during the sync pulse to allow the 9601 to relax.

The data, in addition to being applied to the fall trigger of the 9601, are simultaneously applied to the rise trigger (clock 2) of the 8273. The output of the 9601, in this case $\overline{Q}$, is applied to the "data" terminal of the 8273 which is where this application departs from the norm. The output of the 9601 is clocked through the 8273 by the data pulses. This is contrary to the usual procedure of having the 9601 clock the data into the 8273 for parallel reading. By design, the information being applied to the data terminal of the 8273 waits at the terminal until a pulse clocks it into the 1st register of the 8273. In this case, the datum is the $\overline{Q}$ output of the 9601 which is 1 until the trailing edge of the first pulse changes the state. With the 1 waiting at the data terminal of the 8273, the leading edge

of the incoming 1st data pulse is applied to the "clock 2" terminal, thereby clocking the 1 into the first register. The falling edge of this same pulse puts a Ø at the data terminal. The next data pulse is applied to the "clock 2" terminal at the end of the data time for channel 1. This second data pulse clocks the 1 from register 1 into register 2 and the Ø from the data terminal is placed in register 1. The next data pulse will clock the 1 into register 3 and put a Ø in registers 1 and 2. The data being sought are the length of time the 1 stays in the register and this time is linearlydependent on the value of the resistor being sensed by the encoder. This process continues until the 1 has been shifted serially through all 9 of the output registers of the 8273. Following data time 9, the sync pulse allows the 9601 to relax, and a 1 is placed at the data port of the 8273 to wait for the next pulse train. This system precludes the necessity for a read pulse and a reset pulse as the 1 is merely sequenced out the other end.

The 1 being discussed is the high state of the output port which, for an 8273 is typically 3.4 volts, with a corresponding Ø, or low state, of 0.2 volts. These voltages do not change during the time they are applied; they are either one or the other. The data are the times the output is at 3.4 volts.

Given this type of output, a choice is avaliable as to what way to display it most effectively. It can either be handled digitally or in an analog manner. Digitally, the output would be timed with a clock while the converter

ascends through a sequence of numbers. The number in the converter at the end of the pulse corresponds to the value of the resistor. While this approach is highly accurate, it is difficult to implement when a record of a signal, such as a sinusoid, is desired. Using the analog approach, the output is integrated to obtain an output voltage which is proportional to the length of the pulse, and therefore the value of the resistor (sensor).

This introductory section has summarized the theoretical investigation accomplished by Lt. William Gadino in March of 1974 and published as Ref. 1.

II. ENCODER/DECODER REDESIGN

A. SYSTEM PROBLEMS

Activiation of the system shown in the introduction and reconstructed from data in Ref. 1 was not at an acceptable level of performance. Numerous problem areas and malfunctions were encountered. Each of these had to be overcome before development could continue. The problems encountered were as follows:

1. Entire system was unstable.

2. Indications of Electro-Magentic Compatibility (EMC) failures were evident.

3. Loss of pulses at the receiver was encountered.

4. When demodulated, the information pulses were sequenced through two channels instead of one; e.g., data for channel 2 was in 3 and 3 was in 5, etc.

B. SOLUTION OF SYSTEM PROBLEMS

1. Transmitter/Encoder

The first section investigated was the transmitter/encoder. The waveforms observed in the encoder did not correlate with those shown in Ref. 1. Pulse shapes varied considerably with changes of antenna location, supply voltage and shielding between transmitter/encoder components.

To correct these problems, the transmitter was disconnected from the encoder and an optimum voltage for the encoder's operation determined. This voltage was found to

be 4.2 volts at 80 milliamps, which is within the manufacturer's design recommendations. However, when the transmitter was reconnected, attempts to operate at the optimum voltage of the encoder produced a weak intermittent output with severe signal distortion. This is a critical problem as the unit will be powered by 4.8 volt 500 milliamp hour nickel cadmium batteries which have an operating range of 5.3 to 4.8 volts.

The Heathkit transmitter is designed to operate on 9.6 volts. On Page 48 of Ref. 1, this problem is discussed and it is recommended that the transmitter be optimized for 4.8 volts. Close investigation of the circuit indicated that the optimization procedure had not been accomplished and therefore was attempted here. Initially it was attempted to optimize at 4.2 volts which corresponds to the best voltage for the encoder but this was just too low to be successful. Transmitter optimization for 5 volts was accomplished and a dropping resistor was inserted between points B and C of Figure 8-a to provide the best voltage for the encoder also.

Technically, for proper operation of Q101 (oscillator) Figure 8-b, the base had to be maintained between 2.5 and 3.3 volts; therefore R 102 was changed from 4700 to 2200 ohms which puts the base of Q 101 between 2.9 and 2.6 volts, depending on the battery power supply level, and provides stable oscillator operation. Additionally L 103 was retuned (trimmed) to provide maximum coupling between the power amplifier and the oscillator. With the solid

signal into the power amplifier, L 105 was retuned to provide maximum coupling between the power amplifier and a 36-inch monopole antenna.

When all of these changes were accomplished, the transmitter/encoder was tested over the range of voltages available from a nickel cadmium battery and demonstrated highly stable operation.

2. Packaging

At this point, transmitter/encoder packaging was accomplished. To keep within the size constraints for the unit as nearly as possible, the assembly was placed in a 2-inch by 2-inch by 5-inch plastic box. The connectors used for sensor and power supply access through the package are:

1 Heathkit Part No. 238-31 Connector Block Assembly

9 Heathkit Part No. 238-32 Individual 4 Pin Connectors

1 Heathkit Part No. 432-104 Individual 4 pin Connector

1 Heathkit Part No. 432-103 Individual 4 pin Connector

1 Heathkit Part No. 60-35 Switch

The connector block assembly provides nine separate 4-pin connections. One is used for the power supply in conjunction with the switch, and the remaining eight are used for sensor data channels as shown in Figures 9 and 10.

3. Receiver/Decoder

With the transmitter/encoder package operating with increased power and excellent stability, the receiver/decoder circuitry was investigated. The initial observations showed Preblems 3 and 4, stated at the beginning of this section, persisted and were functions of the receiver/decoder.

The waveform observed at the receiver output, collector of Q5 in Figure 19-a Ref. 1, showed inconsistent amplitude with alternating peaks below the threshold required to turn on the first transistor of the interface circuit, Figure 19-b Ref. 1. This waveform is shown in Figure 11. This problem was intermittent: when observed, both Problems 3 and 4 were present; when not observed, only Problem 4 was present. It was determined that this intermittent inability to turn on the first transistor of the interface circuit caused the loss of pulses to the decoder and was strictly a function of the "off the shelf" receiver.

The initial attempt to solve this problem was trimming of antenna inductor T1, Figure 19-a Ref. 1 to maximize the amplitude of the signal at the collector of transistor Q5 in Figure 19-a. The maximum amplitude obtained was still insufficient to provide stable triggering of the interface circuit; therefore, the interface circuit was redesigned as shown in Figure 12. Resistors R1 and R2 provide a voltage divider network which keeps the base of transistor Q1 at 0.5 volts and coupling capacitor C isolates the receiver from the base of transistor Q6. Any signal greater than 100 millivolts will trigger transistor Q6.

When these changes and adjustments were completed, Problem 3 (loss of pulses) was solved. Observing the output of the interface circuit at the collector of transistor Q7 shows a train of equal amplitude pulses (Figure 13) which is the desired input to the decoder; however Problem 4 (double indexing of data) persisted.

Closer observation of the pulses in Figure 13 showed distortion caused by peak overshoot. The pulse being discussed is the 250 microsecond spacing pulse which goes to the clock 2 rise trigger of the 8273 where it is used for indexing. This was interpreted by the decoder as two or more pulses and manifested itself at the output terminals by indexing the data through more than one channel. This difficulty was easily overcome by inserting a .0047 microfarad capacitor between the collector of transistor Q7 and ground. The capacitor rounded the leading edge of the 250 microsecond pulses slightly and ensured that a single leading edge per pulse was presented to the 8273 for triggering. This eliminated Problem 4 and essentially corrected all discrepancies of a repetitive nature.

The power supply for the receiver/decoder will be located at the ground station, therefore battery operation is not anticipated. An investigation of the power supply effects on the circuit was accomplished with the following results: The power supply must be well filtered as the current surges generated by operation of the 9601 multivibrator may cause voltage fluctuations throughout the receiver/decoder circuitry. These voltage level fluctuations can be interpreted by the 8273 as data/spacing pulses. It was found that a parallel combination of 120 microfarad and 0.1 microfarad capacitors, when used with a Hewlett Packard model 6218A regulated power supply, filter out any low and high frequency components sufficiently to ensure satisfactory operation.

4. Testing

With all circuit redesign completed, the system (encoder/transmitter, R. F. link, receiver/decoder) was operated for extended periods of time. The following observations were made:

a. stable output

b. no cross channel modulation

c. properly sequenced data

d. input/output data correlated precisely with predicted parameters [Figure 24, Ref. 1].

III. INPUT SENSOR CONFIGURATION

The intent of this project is to measure aerodynamic parameters and relay the information, in real time, to a ground station for evaluation and recording. It was felt that the minimum data required to prove the system and indicate the aircrafts activities were:

1. angle of attack
2. yaw angle
3. airspeed
4. altitude
5. acceleration in any single plane

The first consideration was where the sensors should be located on the aircraft inasmuch as all the physical considerations of mounting and interaction of components will determine their usefulness. As the aircraft had not been built, it was felt that a universal wing pod arrangement which could be incorporated into any aircraft would be most advisable. This would permit selection, investigation and initial calibration of the sensor package without the requirement to first build the aircraft. Additionally, fuselage mounted sensors are subject to degrading effects of turbulent airflow caused by propwash, and by castor oil contamination caused by exhaust gasses of typical two-stroke model aircraft engines. Therefore a boom design, with a pod incorporated,was selected. This apparatus is shown in Figure 14.

A. PRESSURE SENSOR LOCATION

The dynamic pressure sensing system is contained in the sting at the center of a circular wing. This arrangement will provide ambient data which are relatively independent of aircraft attitude. The static pressure ports are located on the boom, midway between the leading edge of the wing and the pod. This location should provide the smoothest possible airflow over the static port and will minimize position error.

The pitot static system sensors are attached to tubing that leads from the sensing position, back through the boom, into the wing and from there to a fuselage or wing mounted pressure transducer.

B. ATTITUDE SENSOR LOCATION

Behind the circular wing is the instrumentation pod for the aircraft attitude sensors. Angle of attack and yaw angle indicator vanes are attached to 360-degree, low torque, 100K ohm pots with linear taper. Therefore the vanes position is measured by the linear variation of the resistance of the pot. It is anticipated that the aircraft will be operating at speeds as low as 20 to 30 knots during tests in the stall region. In order to ensure the highest resolution of aircraft attitude data with the small dynamic pressures characteristic of these low speeds, oversize vanes and extremely low torque potentiometers have been utilized.

C. ACCERLERATION SENSOR LOCATION

Acceleration sensor location will be near the aircraft center of gravity and therefore will be more precisely determined after aircraft construction.

D. TRANSDUCER SELECTION

1. Attitude Sensors

The angle of attack and yaw angle transducers were selected to cover the range of resistance values the encoder was designed for. Primary considerations were low torque requirements and high resolution.

2. Accelerometer

The accelerometer chosen has a potentiometric output which greatly simplifies the application. The Edcliff part no. 120296-1, with a range of $\pm$ 15 Gs meets the input requirements of the encoder and covers the range of interest with acceptable resolution.

3. Pressure Sensor

The size, weight, and power constraints which apply to an RPV, and in particular to an RPV aircraft with less than a 6-foot wingspan, greatly reduce the transducer selection. A thorough study was made of the pressure transducer market and the possibility of locally manufacturing the required transducers was considered. It was decided that a commercially manufactured miniature transducer would be most cost effective. Of the many manufacturers considered, Kulite Semiconductor Products Inc. emerged as the sole source of miniature pressure transducers, within the price

range, that satisfied the constraints mentioned above. The transducer pressure range calculations for both altitude and airspeed are shown in Table I Appendix C. Based on these calculations, it was decided that the altitude data could be obtained with a Kulite model number TQS-360-25 pressure transducer with a range of Ø to 25 PSIA. The airspeed sensor is a Kulite model number IPT-1000-1 pressure transducer with a range of Ø to 1 PSIG. This pressure range provides a speed range of Ø to 348 feet per second or 206 knots, which is adequate.

The difficulty with these transducers is they are not potentiometric. A potentiometric pressure transducer of miniature size, with the desired accuracy and temperature stability, is not commercially available for other than a prohibitive cost. Therefore, the encoder system had to be adapted to the voltage-output sensors.

After considering many approaches, such as transducer-driven servos attached to potentiometers, and elaborate circuits to transform the signal to a compatible state, the design shown in Figure 15 was adopted. This circuit uses a constant current source identical to the original encoder design. As mentioned earlier, the rate of discharge of the 555 timer capacitor is determined by the resistance in the emitter circuit of the transistor. The current which drains the capacitor is maintained at a constant level for the given event by a constant potential at the base of the transistor. In this application, a fixed resistor is placed in the emitter circuit and the potential at the base of the

transistor is determined by the transducer, thus the transistor, Q1, acts as a constant current source. While the controlling elements, the transducers, do vary with the aircrafts movements between samples, their change is negligible when compared to the sample time. The term "constant current source" is still applicable. By adopting this circuit, the basic design and multiplexing scheme is preserved while introducing non-potentiometric sensors into the system.

For each voltage-output transducer used, a circuit, as shown in Figure 15, is required. The values of the components which amplify the output of the transducer to the level required to control the decay rate of the 555 timer capacitor must be calculated. This development and calculation scheme is demonstrated here using the Kulite model TQS-360-25:

a. Select a transistor similar to the one being used as a constant current source for the potentiometric transducers.

b. A resistor for the emitter circuit must be selected which will provide the proper pulse lengths with various transistor base potentials. This can be done either analytically or experimentally. Analytically, the transistor characteristic V_{be} vs I_c and the current required to discharge the capacitor of the 555 timer are used. Capacitor discharge current is calculated as follows:

$$I = C\frac{dV}{dt} \quad \text{For this case } C = 0.05 \text{ microfarads}, \; dV = 1.67 \text{ volts}$$

$$\text{For 1 millisecond pulse } I = 0.05\times10^{-6}\,\frac{1.67}{.001} = 83\,\mu\text{amps}$$

Experimentally, the base voltage may be varied, and a plot of base voltage vs. pulse width for different external resistances may be determined as shown in Graph 1. Selection of the external resistance selected in this case is 10K ohms. The voltage range of the base of the transistor is defined by the plot.

c. The transducer output voltage must be calibrated over the range of interest. The calibration of the TQS-360-25 was accomplished with a voltmeter of appropriate range and a manometer in conjunction with a pressure/vacuum pump. This data is shown in Graph 2. The transducer voltage output range is determined from this graph.

d. In the aircraft, the voltage available is +5 volts D.C. An operational amplifier (op-amp) requires a plus voltage, a minus voltage and a Ø, or reference, voltage. In this application, the op-amp is allowed to float with 2.5 volts on the power supply (battery) being Ø volts for the op-amp. The op-amp operates on $\pm$ 2.5 volts. Therefore the voltage output of the op-amp varies from the +2.5 volt potential which is the Ø reference for the op-amp depending on the input voltage.

e. Given the voltage output range of the transducer, and the base voltage range of the transistor (Graphs 1 & 2) an amplification factor for the op-amp is determined. Using

the ratio of R2 to R1 as op-amp amplification factor, R1 and R2 may now be chosen.

f. To place this voltage change at the proper level for the transistor, a voltage divider circuit, R3 and R4, is used. R3 and R4 may be calculated using the equation

$$V_{out} = V_{in}\left(\frac{R3}{R3 + R4}\right)$$

g. Notes on pressure transducer calculations

(1) Since the op-amp inverts, the transducer output leads may require reversal to obtain the proper range.

(2) As this circuit is placed in parallel with the existing circuit, it is not energized until selected by the 74145. See Figure 8-a.

(3) Base voltage range and resistance value are peculiar to the specific transistor used and are independent of the transducer output.

IV. OUTPUT SIGNAL CONDITIONER

As previously described, the data at the output terminals of the decoder are square waves of varying length. As also mentioned, these data can either be processed digitally or in an analog manner. In view of the desirability of chart recordings and dial indicators, which are inherently analog devices, the analog process was selected.

On Page 50 of Reference 1, a discussion of possible processing circuits, both digital and analog, is begun. These circuits were not considered feasible due to their complexity, high cost, and component inavailability. An investigation was initiated into alternative digital-to-analog converters.

A. PROBLEM DEFINITION

The first attempt focused on using an operational amplifier to integrate the output signal from the decoder. This approach eventually proved unproductive. The unique application of Integrated Circuit (I.C.) technology used in the design of the decoder system did not require either a reset or clock pulse for its operation. This was the key to the decoders simplicity, low power requirements, and low cost. It was also the factor that defeated the attempt to use the op-amp as an integrator since the circuity required to provide either the reset or clock function was untenable.

B. SOLUTION

Looking to simplicity in conjunction with the constant current source scheme of the encoder, the circuit shown in Figure 17 was devised. This circuit charges capacitor C linearly through the constant current source, Q9, while the decoder output is high. The charge level of the capacitor is therefore linearly dependent on the length of the output pulse, the desired result. Additionally, the 741 op-amp provides a high impedance buffer to prevent the capacitor from discharging should the output be connected to a low impedance device. When the output is low, transistor Q9 is in cutoff, and the potential on the capacitor remains essentially constant until it is reset. Referring again to Figure 17, reset is accomplished by turning on transistor Q10, which provides a low resistance discharge path for the capacitor. Transistor Q8 is an inverter which allows the use of a positive reset pulse on the PNP transistor Q10. The output waveforms are shown in Figures 18 and 19.

It is also observed in Figure 19 that a discontinuity exists during the reset and charge operations of the capacitor. In order to minimize the affect of this discontinuity on the output voltage level, the reset function occurs immediately prior to the data pulse: Thus in a 9 channel system, the discontinuity is present less than 15% of the time. Because of the averaging affect of the normal readout devices,this discontinuity is largely ignored. Graph 3 illustrates the results of tests for linearity. The predicted correlation between pulse width into the output

signal conditioner and the voltage output generated is proven.

To accomplish the reset function, which was the difficulty with other circuits, without additional circuitry or timing, each channel uses the previous channel's data pulse as its reset pulse. To make the system totally independent of external timing, channel 9 resets channel 1 and a closed loop is generated. This arrangement is shown schematically for three channels in Figure 20.

C. CALCULATIONS

Development of component values was accomplished in the following manner:

1. Capacitor Selection

The output signal conditioner will be powered with a regulated power supply designed for use with integrated circuits. These power supplies provide $\pm$ 15 volts D.C. Based on the range of possible voltage levels the capacitor will be able to attain with this power supply (0 to 15 volts) and the period of the applied data pulse (1 to 2 milliseconds) it was decided that an output swing of about 9 volts would provide a good range of values for an input to a typical readout device.

Given V_{cc} = 15 volts

dV = 9 volts

dT = 3 milliseconds

$$I_c = C\frac{dV}{dT} \quad \frac{I}{C} = \frac{dV}{dT} = \frac{9}{0.003} = 3 \text{ volts/microsecond}$$

Choosing $C = 0.5 \times 10^{-6}$ gives $I_c = 1.5$ milliamps. This is a reasonable value for the collector current of the transistor.

2. Emitter Resistance

With the capacitor charge current determined in step 1, the emitter resistance required is calculated. The data pulse at the base of the transistor is 4 volts and taking into account the 0.6 volt drop between the base and emitter, V_{be}, at saturation, the voltage across the emitter resistor is 3.4 volts. Therefore the emitter resistance must equal 2200 ohms.

$$R_e = \frac{V_e}{I_e} = \frac{3.4}{0.0015} = 2200 \text{ ohms}$$

The emitter resistance requirements for Q7 are the same.

3. Discharge Time

The mechanism used for capacitor discharge is to apply the data pulse from the previous channel as a trigger (as discussed earlier). Discharge must be rapid to ensure complete elimination of any previously stored energy in the minimal time available. A discharge current, compatible with the transistors published characteristics, is 150 milliamps. Using the values determined in step 1, the discharge time is:

$$I = C\frac{dV}{dT} \qquad dT = \frac{C\,dV}{I} = \frac{(0.5 \times 10^{-6})(9)}{0.150} = 30 \text{ microseconds}$$

This time is considered acceptable as it is less than or equal to 1% of the minimum pulse width.

4. <u>R_c Selection</u>

R_c is not critical but must provide the voltage required to turn on Q8. When transistor Q7 is on, it attempts to pull the base of Q8 down toward +4 volts, a change of minus 11 volts. However, since $V_{be_{sat}}$ for Q8 is on the order of -0.7 volts, saturation of Q8 is ensured and provides a discharge current of at least 150 milliamps. Thus the value of 10K ohms is used.

V. ANTENNA CONFIGURATION

With the electronics portion of the MDTS system completed, a study of the electromagnetic compatibility effects of having a digital transmitter and receiver, operating simultaneously on this small platform, was begun. With the actual physical design of the platform undecided, a general approach, which can be applied to any RPV, was selected.

Concentrating on antenna configuration, a "state of the art" wire simulation model of the aircraft was developed. The model was evaluated using the Ohio State University Antenna Analysis Program. This program, as modified for use at the Naval Postgraduate School, is documented in Ref. 4. The wire simulation model is diagramed in Figure 21.

After a number of computer solutions of the problem, which are summarized in Chart D, it is recommended that the transmitter antenna in the aircraft be made a half-wave dipole extending out each wing, rather than the monopole used in these tests. This configuration will result in a three-fold increase in the radiation resistance, and a reduction of two orders of magnitude of the non-radiated reactive components. Greater output power for the applied voltage and more consistent reception of data will result.

The relative-position effects of the receiving and radiating elements were evaluated using a simulated 50-ohm load at various points in the receiving antenna. Observing the currents induced in the 50-ohm load, and comparing them

with the predicted currents induced by the normal received signal, shows the level of mutual interference to be expected. The simulation results indicated mutual interference will not be a particular problem, and in the final analysis, antenna configuration will be primarily a physical consideration.

VI. CONCLUSIONS

The theoretical Miniature Digital Telemetry System, initially designed by Lt. William Gadino, has been developed into a highly stable and reiable system. Unique ideas have been adapted into the device which allow it to accept various types of transducers as its input and provides an output which is compatible with readily available readout devices. The development of this experimental model into a working useful device has been accomplished while keeping within the original size, weight, and power constraints which are basic to the anticipated application.

APPENDIX A

SELECTED EXCERPTS FROM REFERENCE 1

Appendix A constitutes selected excerpts from Ref. 1 which are referenced in the text. They are presented here for the convenience of the reader.

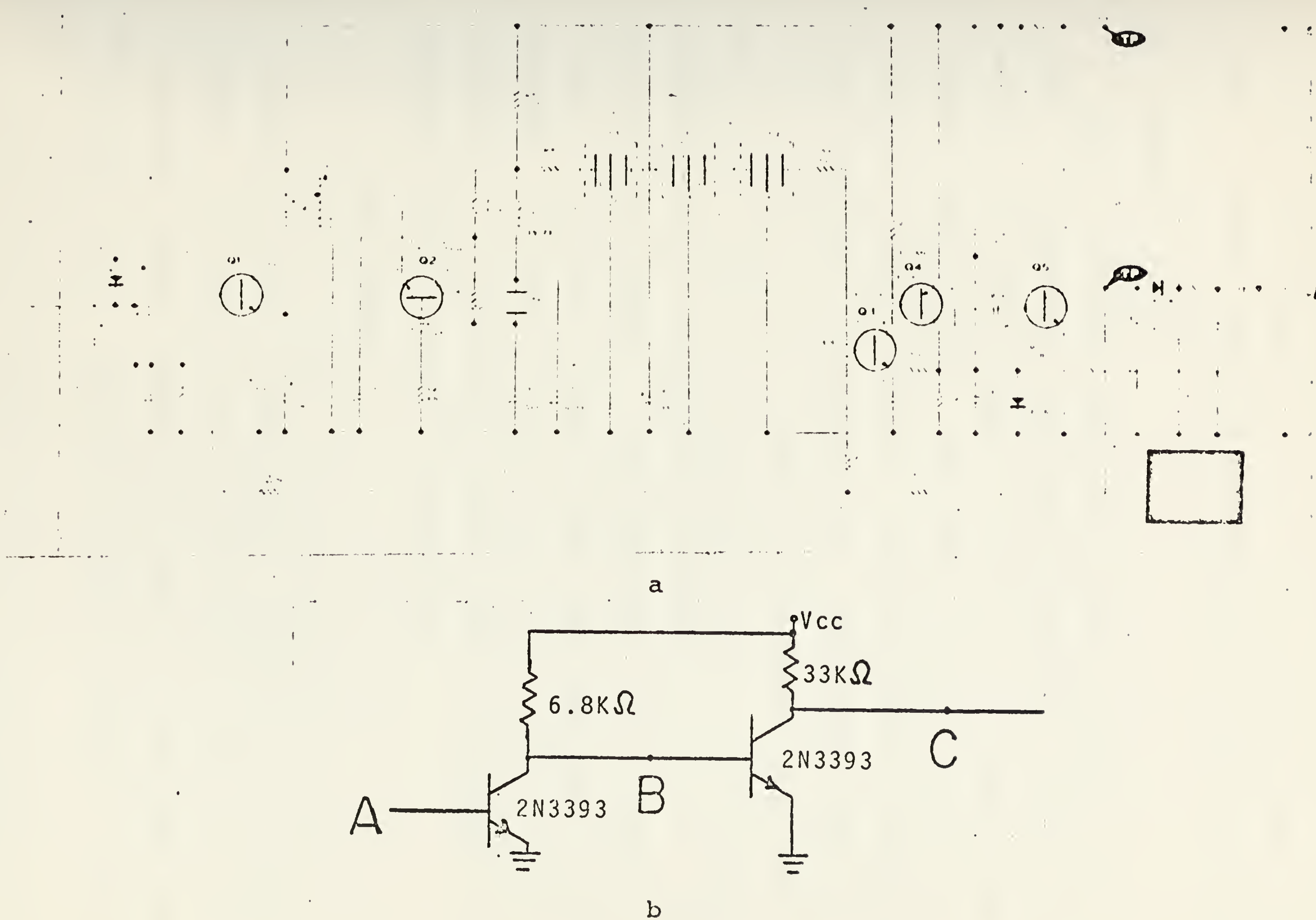

Figure 19. a) Heathkit 54MHz Receiver, b) Decoder Interface Circuitry

Q2's base drops below approximately 0.6Vdc Q2 shuts off causing the collector to rise to 4Vdc thus providing a pulse train of proper amplitude and polarity to drive the decoder.

C. READOUT DEVICES

Before choosing a particular type of display, it is imperative to understand a significant difference between a system employing the TTL or Linear Encoder and a system with the Digital/Linear Encoder. The former encoders operate in a synchronous manner, that is, the decoded channel outputs are always separated by a fixed time. This assumes that the clock signal from the aircraft control system is fixed.[2] The latter encoder is asynchronous in that the individual channel outputs are separated by times that vary as a function of the other channels. This means that similar readout devices or techniques cannot be used with the linear/digital encoder. In view of the fact that this encoder is better suited for the application desired here, a discussion of compatible readout devices is appropriate.

1. Servo Readout

Figure 21 shows the block diagram for a typical servo control unit which is commercially available from Heathkit Company. The servos translate the signal pulses from the individual channel outputs into positive or negative voltages that drive a motor. The motor shaft is coupled to linear and

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[2] The majority of Remote Control systems commercially available for model control are fixed frame rate systems.

(Page 50, Reference 1)

rotary rack gears as well as a variable capacitor that controls feedback to the multivibrator. When a difference signal is sensed (at point A) the motor drives the rack gears. As the gear train turns the capacitor plates turn such that the multivibrator output pulse width matches the incoming signal pulse width. Because the two pulses are opposite in polarity (equal in amplitude) there is no longer a difference pulse to drive the motor. The servo unit is directly compatible with the decoder circuitry explained in section III because a) the servo operates with a channel signal level of approximately three volts which is similar to typical output levels from the 8273 shift register and b) the servo was designed for use with radio control equipments where the channel pulses vary from one-two milliseconds.

The servo unit receives power from a 4.8Vdc supply making it ideal for field work. The rotary wheel output can be used to position an indicator over a range of approximately 100 degrees.

2. Digital-to-Analog Readout

The following was designed to take the channel outputs from the decoder and provide a voltage output proportional to the channel pulse widths. The circuit is configured with the following IC's: Signetics 555 Timer, N7404 Hex Inverter, 74279 Quadruple $\overline{S}$-$\overline{R}$ Latches, uA741 Op Amps, and National DM7552 Decade Counters with Latches.

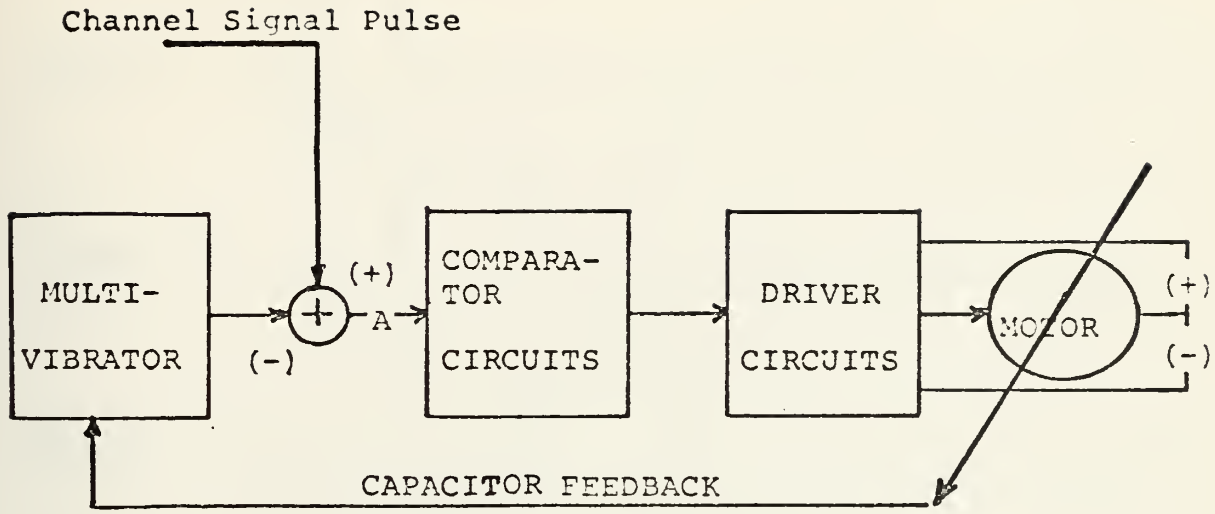
The 555 functions as the system clock. The various channel counters are incremented by the clock pulses whenever

(Page 50, Reference 1)

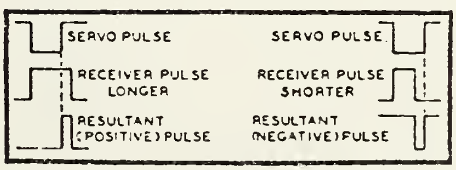
the proper channel output pulse is present. The clock rate is set at 100 pulses/ms (this gives 1% accuracy), hence if a decoder pulse is HIGH for .5ms the counters would hold the BCD number 50. The BCD counter outputs are then fed to a weighted resistance ladder which, in turn, form the input resistance for the Op Amp. The Op Amp drives a meter movement such that the output voltage is directly related to the BCD number stored in a channel counter. If two counters are cascaded any number from 0-99 can be accumulated. Since the channel outputs vary from one-to-two milliseconds, a minimum of 100 counts will always be received. After 100 pulses are counted, a terminal count (TC) is generated and the counters will start over at zero and count up to 99 depending on the pulse width of the input.

The actual operation of the circuit is best described with the aid of the timing and block diagrams of figures 22 and 23. Assume that channel three had the BCD number 88 stored in its counter when channel one's output goes HIGH. After 100ms the TC output from channel one's counter is generated. This pulse is then inverted (via the 7404) and tied to the $\overline{R3}$ input of the 74279. This drives Q3 low causing the latches in channel three's counter to "lock" up. The data paths between the counter outputs and the BCD outputs are now inhibited. This means that the BCD number 88 is locked in buffer registers even though the counters and respective TC outputs are still operable. After channel two has been on for one millisecond, its TC pulse is generated clearing

(Page 50, Reference 1)



(a)



(b)

Figure 21. Typical Servo Unit, (a) Block Diagram
(b) Waveforms

(Page 50, Reference 1)

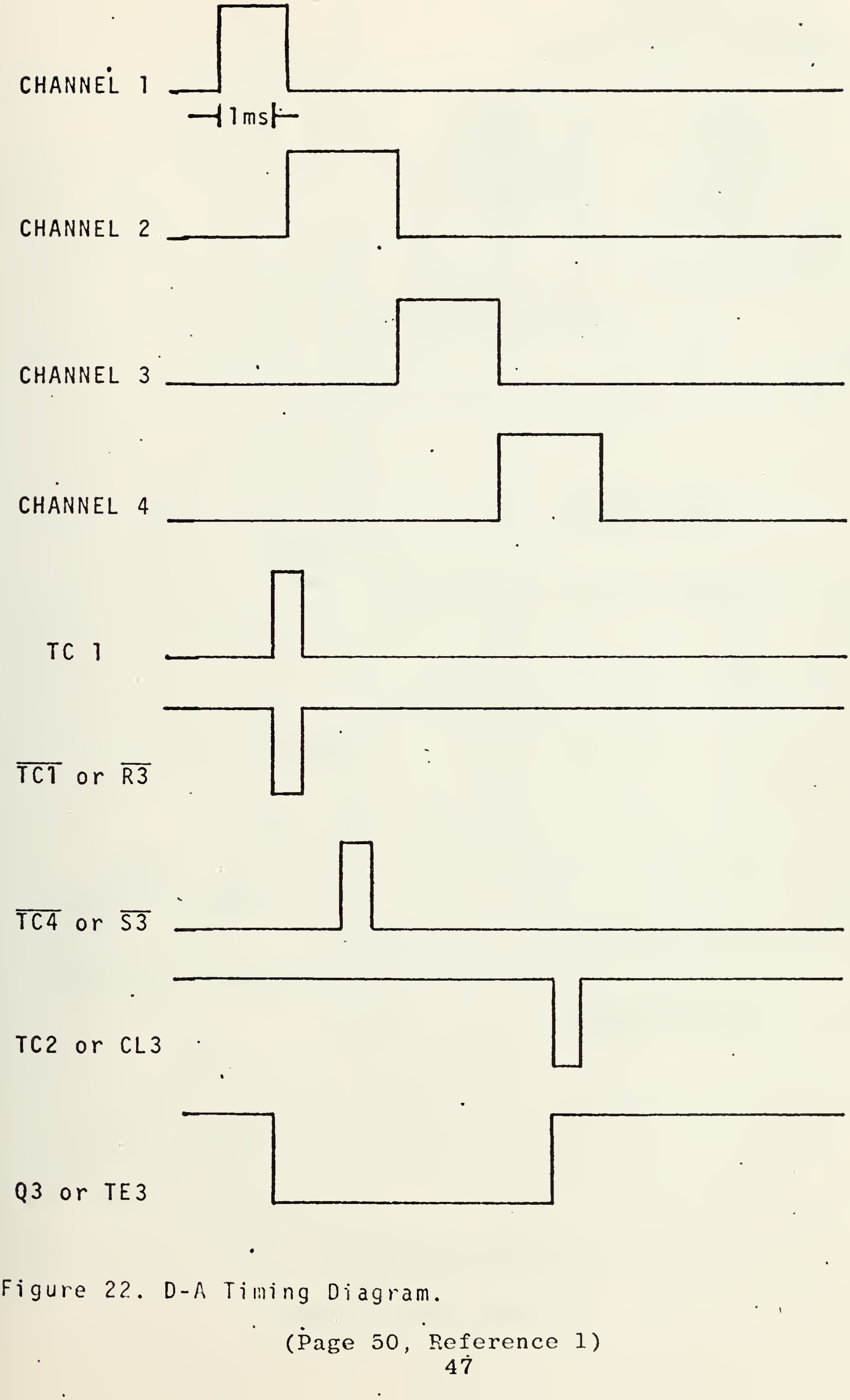


Figure 22. D-A Timing Diagram.

(Page 50, Reference 1)

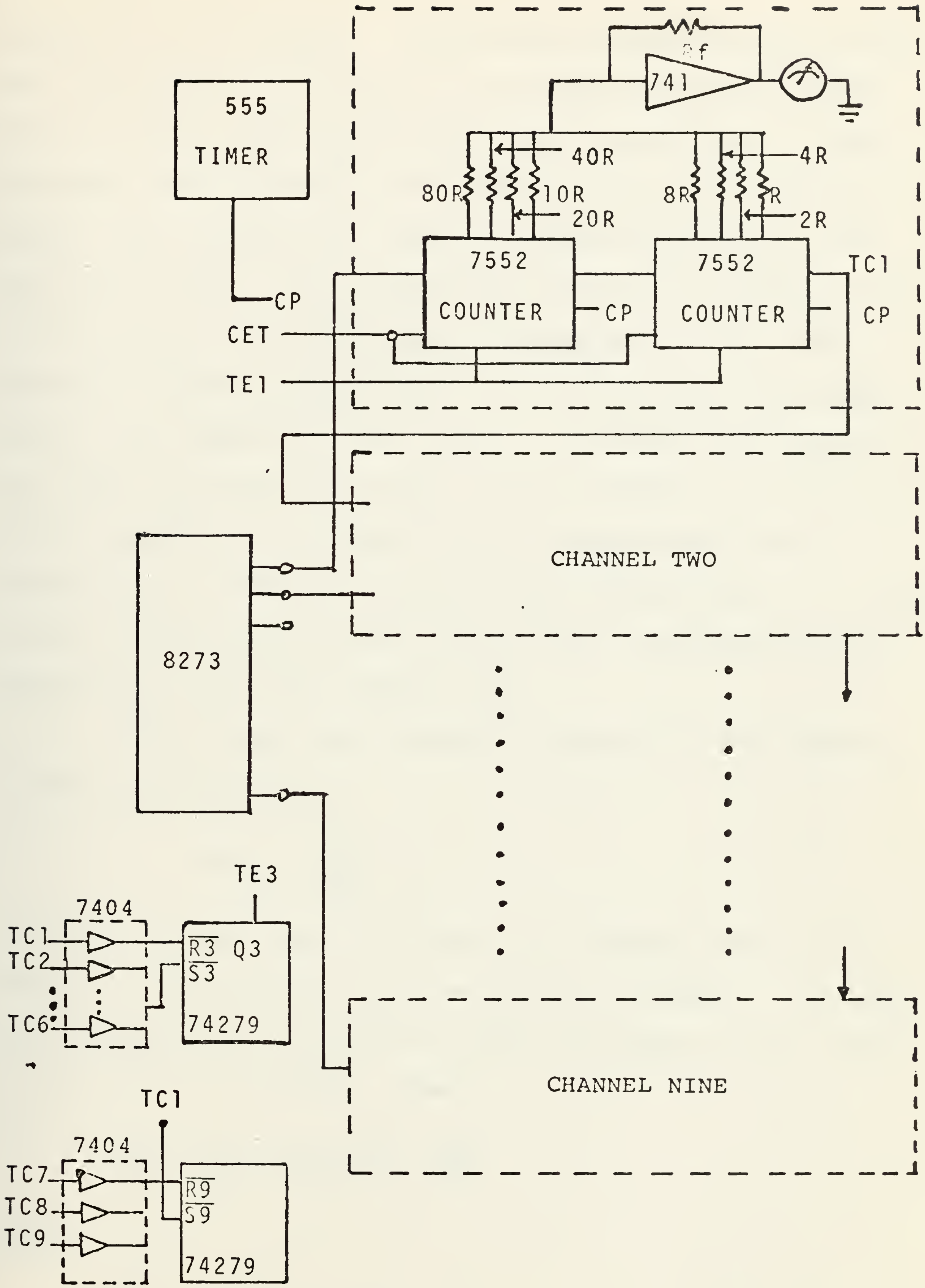


Figure 23. Digital-to-Analog Readout Device.

(Page 50, Reference 1)

channel three's counter. Next channel three's input arrives and a new number is stored in its counter (the BCD outputs still contain 88). The TC pulse from channel four is then inverted and tied to $\overline{S3}$ of the 74279 causing Q3 to go back HIGH. This enables data transfer between the counters and the BCD outputs. If a count other than 88 was entered a new voltage appears at the output of the Op Amp. This timing sequence allows a number to be held in the output registers while a new sample is being taken. In effect four channels are used to provide the timing for one channel. If channel nine's operation were looked at its counter would be: a) latched by the inverted TC pulse from channel seven, b) cleared by the TC pulse from channel eight, and c) unlatched by the inverted TC pulse from channel one.

The Op Amp output voltage is related to the counter outputs by the equation:

$$Vout = \frac{-Rf}{Req} Vin$$

The value for Rf should be chosen so a desired Vout is obtained for the MAX Req from the resistance ladder. The maximum resistance is determined by the BCD number 99 (i.e. pins A_0, D_0, A_1, D_1 are HIGH). Then,

$$Req = \frac{1}{80R}+\frac{1}{10R}+\frac{1}{8R}+\frac{1}{R} = \frac{80R}{99}$$

hence

$$Rf = \frac{Vout}{Vin}\,\frac{80R}{99}$$

(Page 50, Reference 1)

If the counter holds the BCD number 6, Vout is:

$$\text{Vout} = \frac{\frac{80R}{99}}{\frac{1}{40R}+\frac{1}{20R}}\,\text{Vin} = \frac{6}{99}\text{Vin}$$

or if the counters held the BCD number 47 then Vout is:

$$\text{Vout} = \frac{\frac{80R}{99}}{\frac{1}{80R}+\frac{1}{40R}+\frac{1}{20R}+\frac{1}{2R}}\,\text{Vin} = \frac{47}{99}\text{Vin}$$

(Page 50, Reference 1)

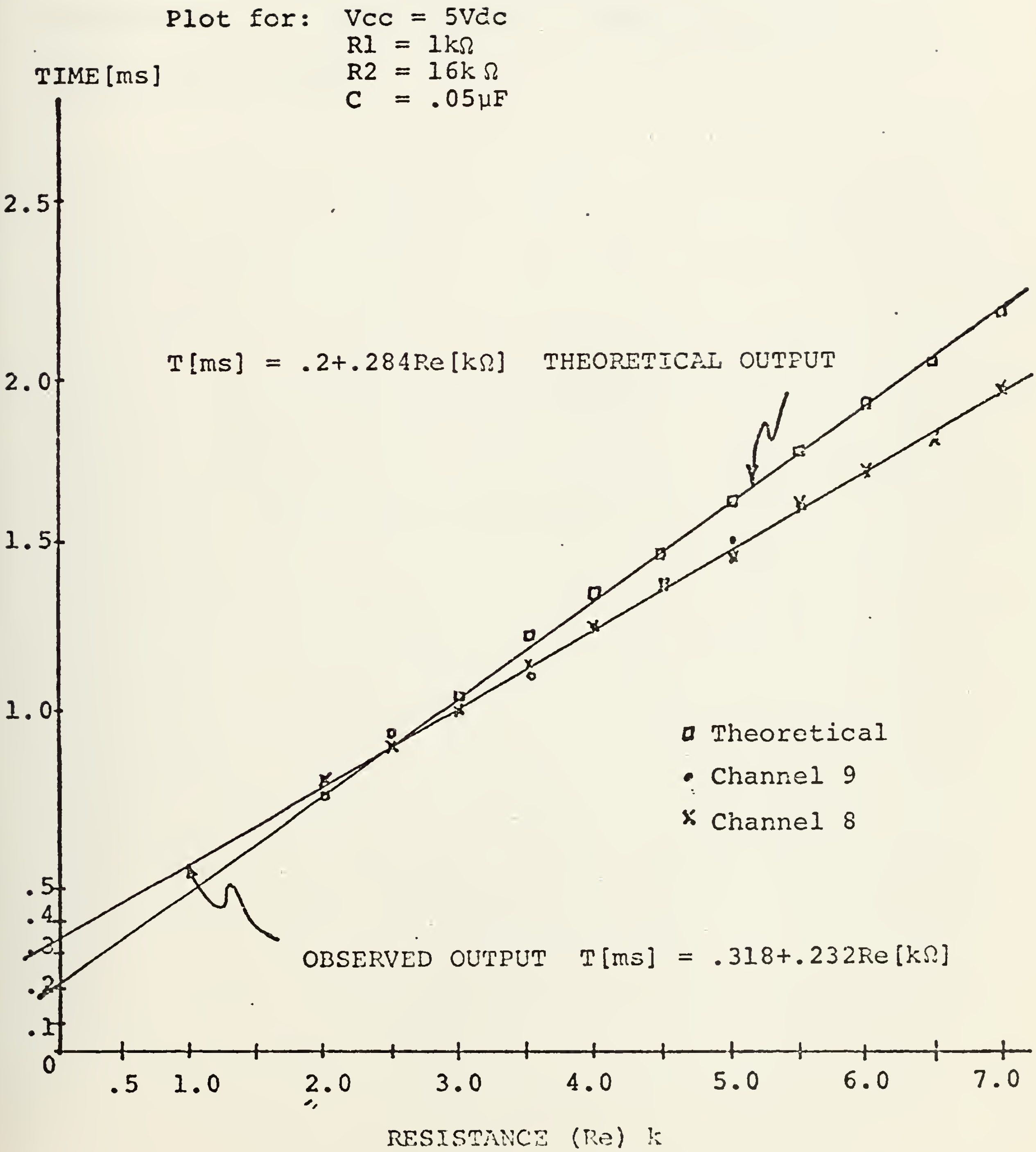


Figure 24. Observed versus Theoretical Encoder Outputs

APPENDIX B

FIGURES, CHARTS, AND GRAPHS

Appendix B includes the figures, charts, and graphs referenced in the text material. These are presented in chronological order.

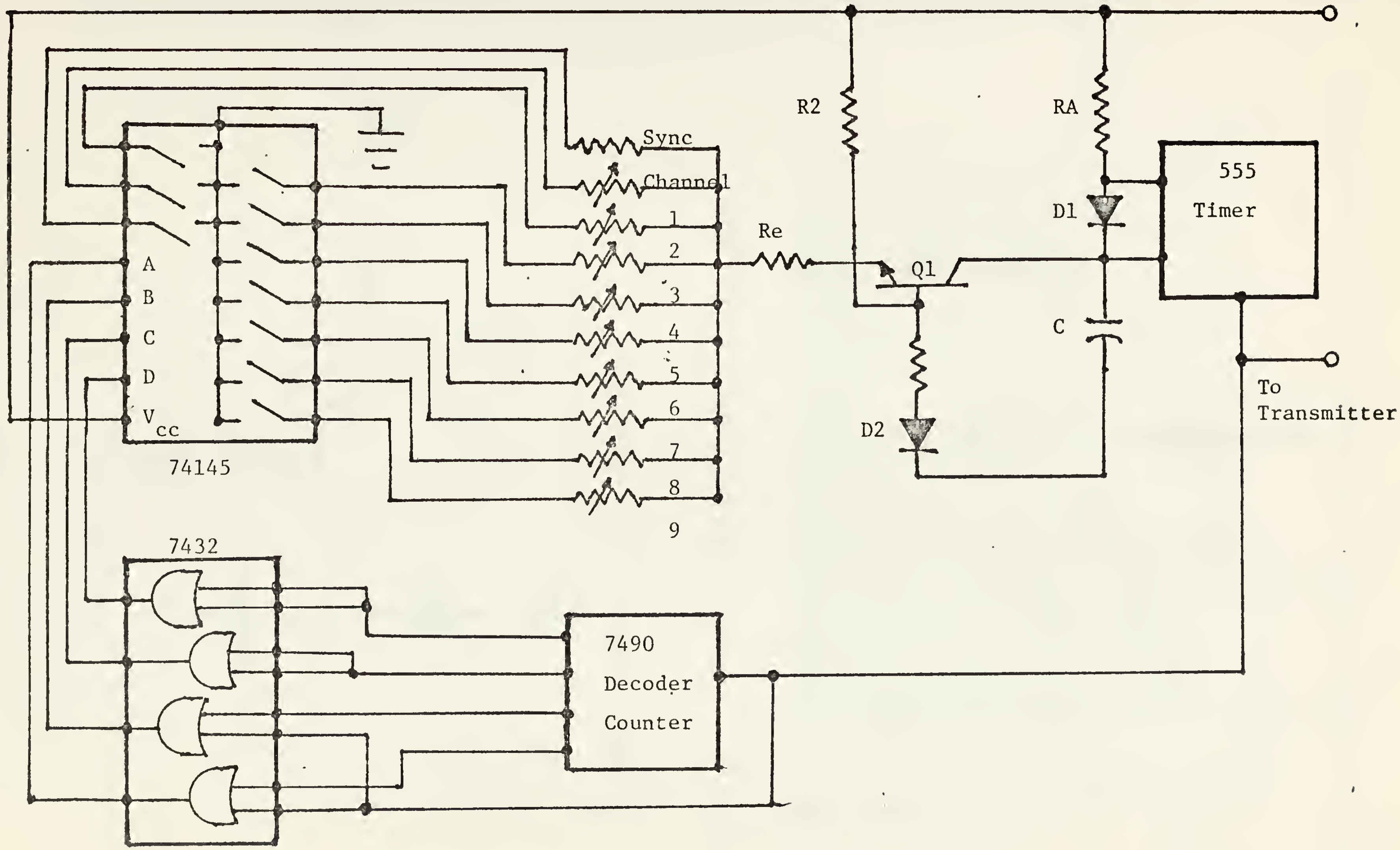


Figure 1. Digital/Linear IC Encoder

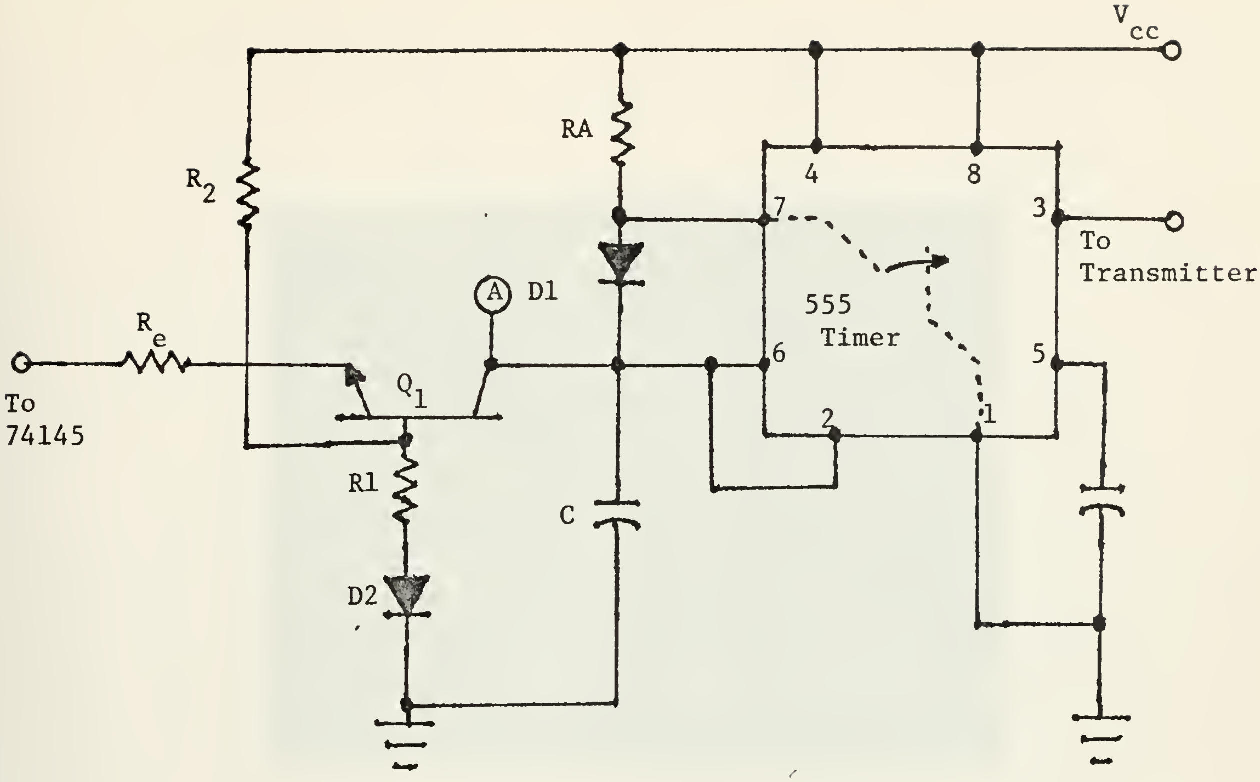


Figure 2. 555 Timer Operation

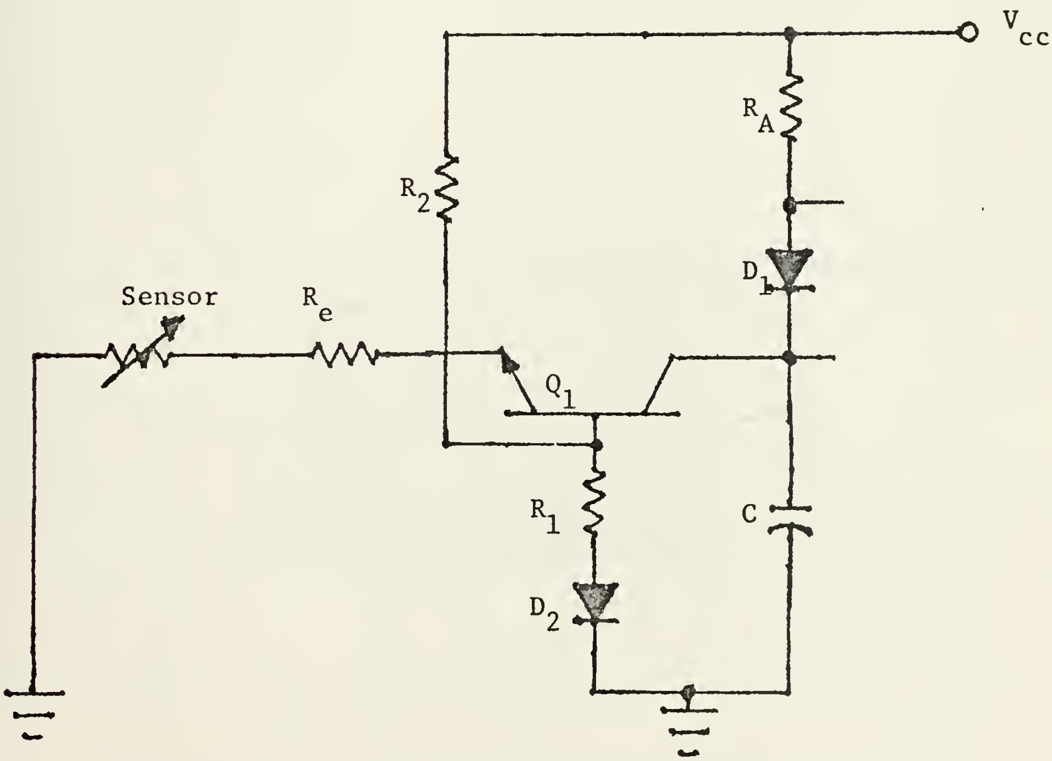
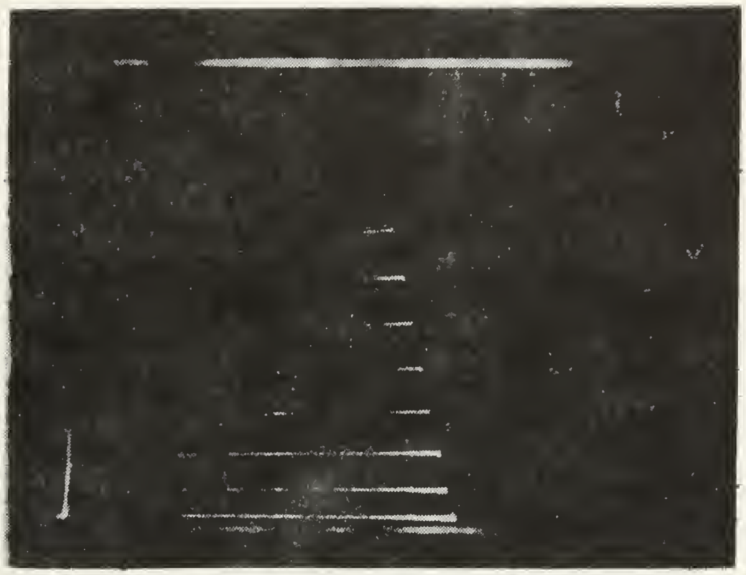


Figure 3. Constant Current Source



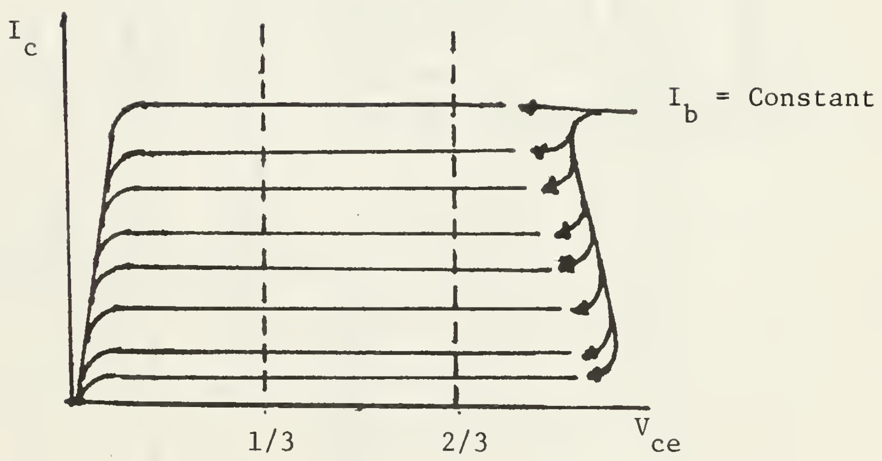


Figure 4. Transistor Characteristic Curves

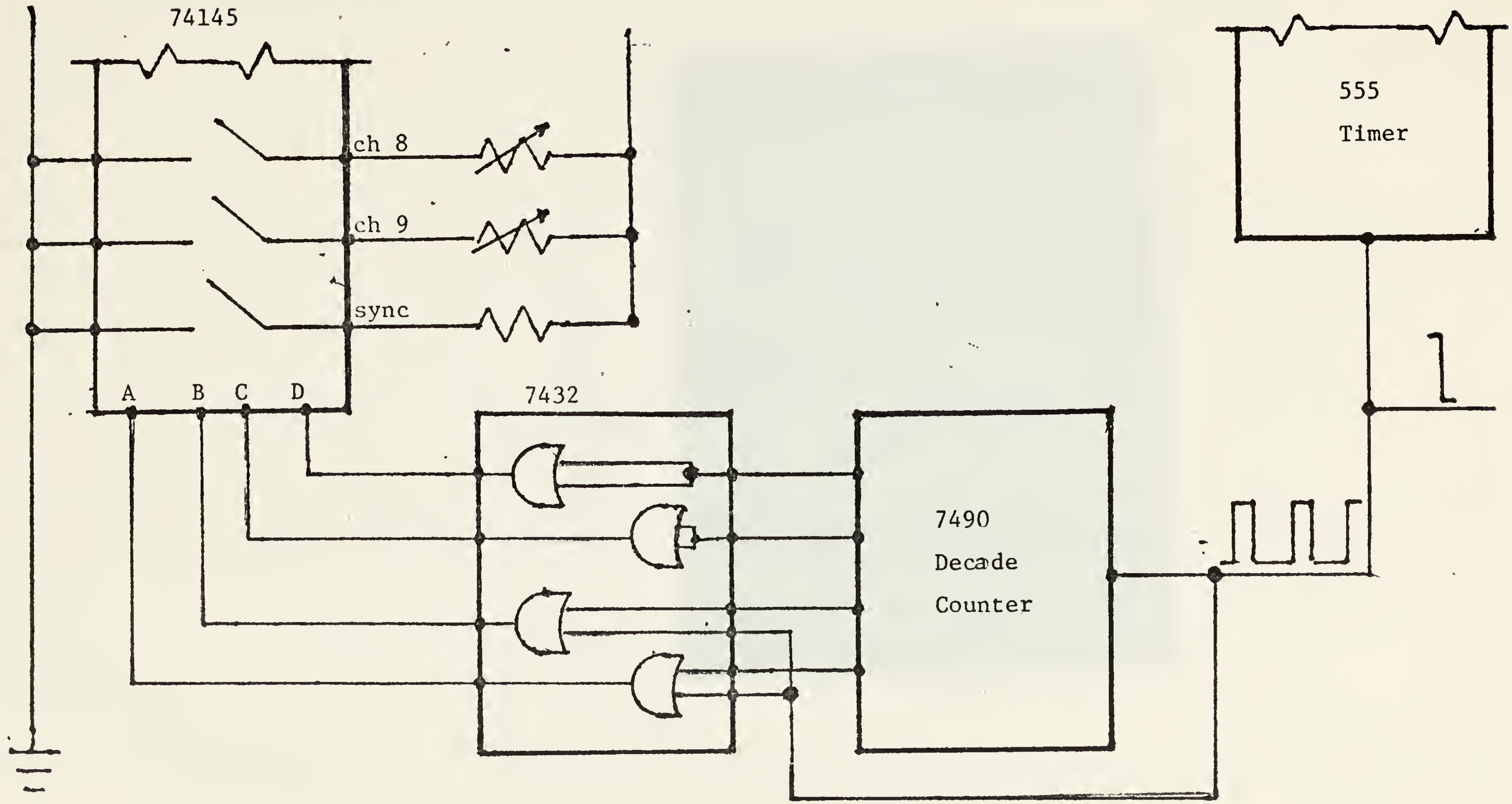


Figure 5. Multiplexer Circuit

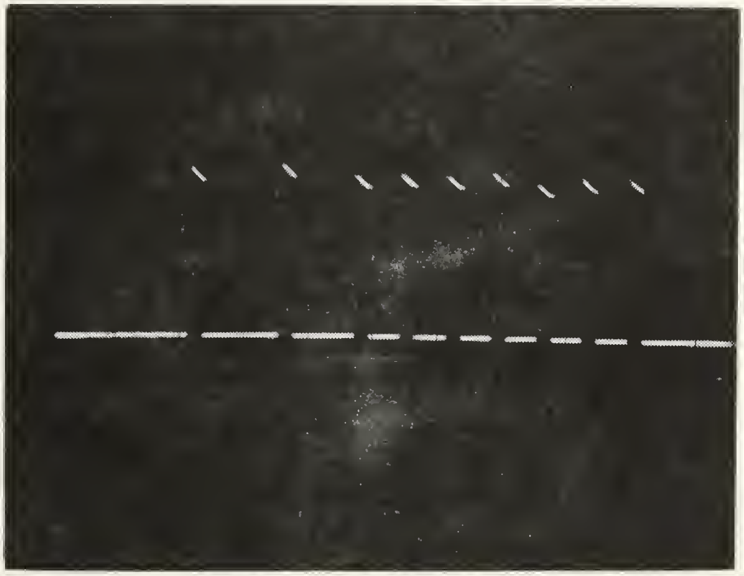


Figure 6. 555 Timer Output

ENCODER/TRANSMITTER OUTPUT CHART

$T_r = 250\,\mu sec$ $T_d = 1-2\,ms$ TOTAL CYCLE $\approx 18\,ms$ $f \approx 60\,Hz$

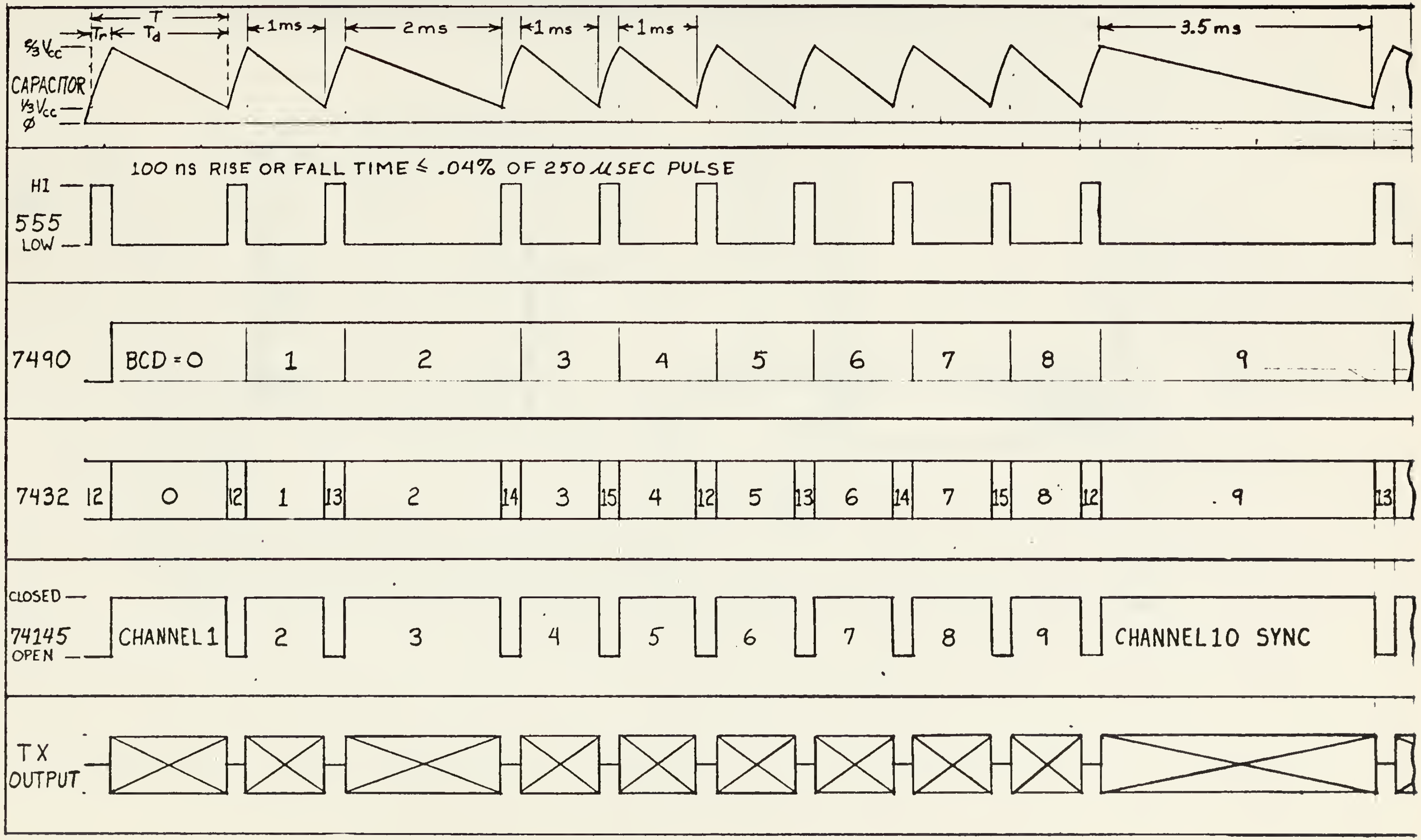


Chart A

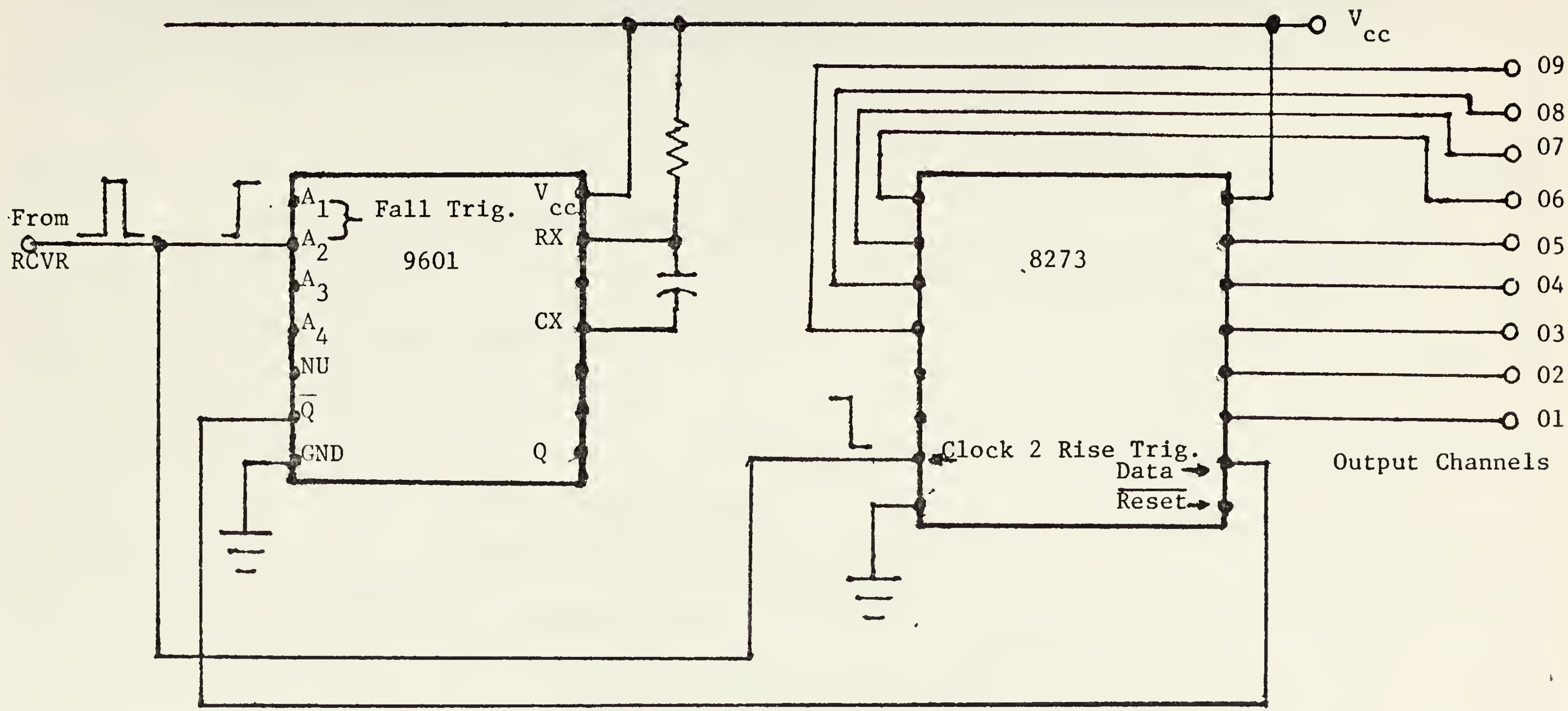


Figure 7. Decoder Circuit

RECEIVER/DECODER/SYSTEM OUTPUT CHART

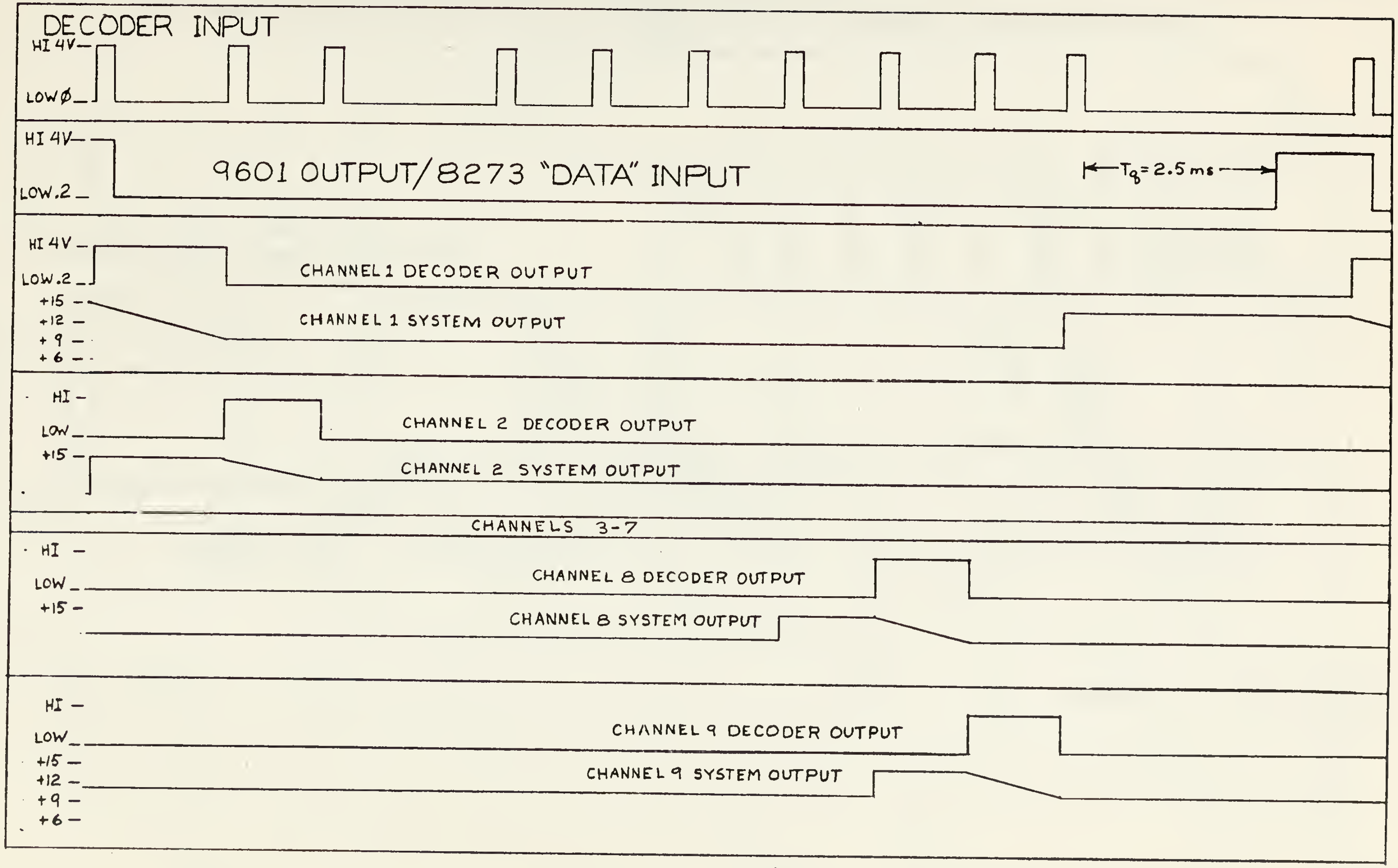
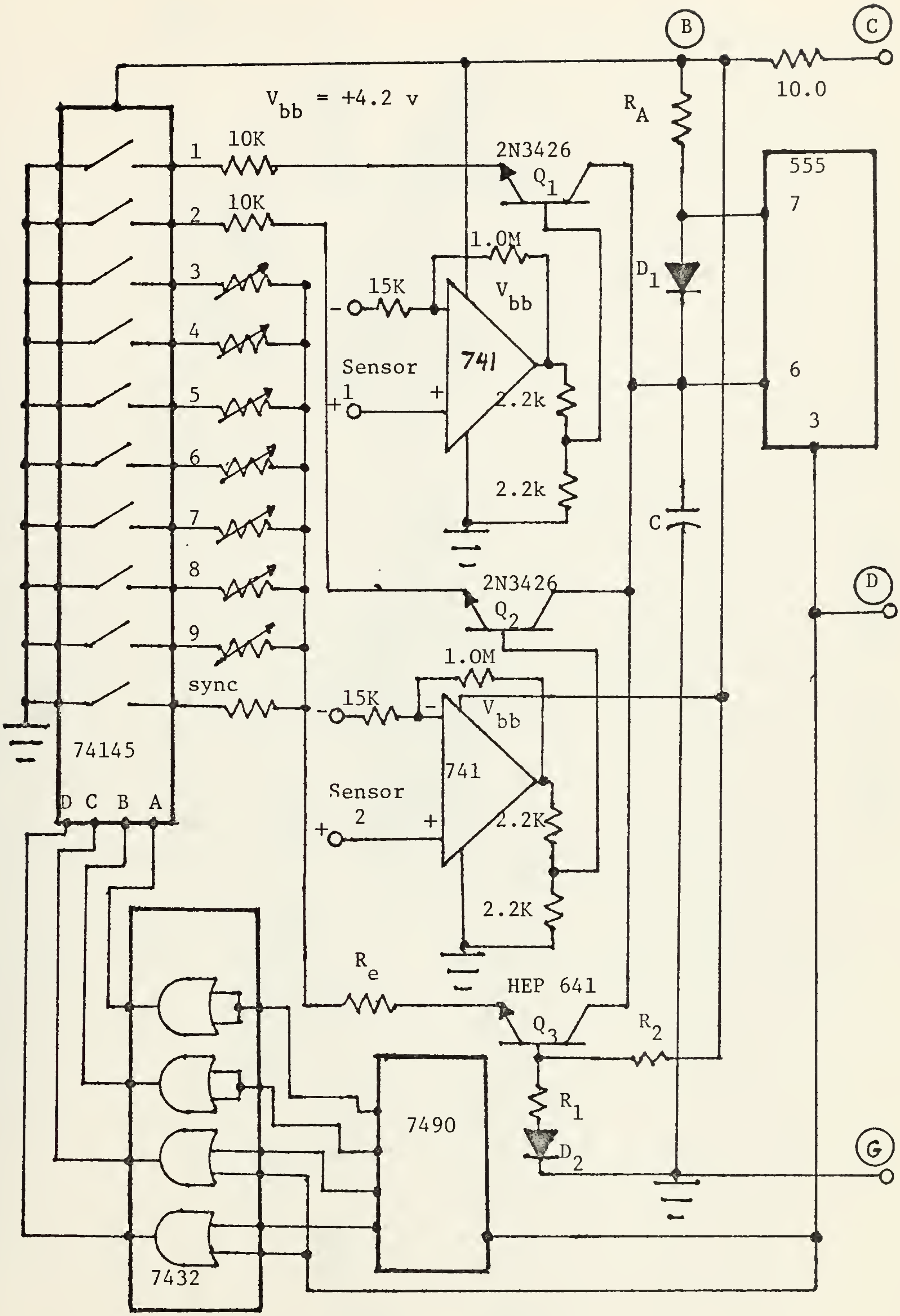


Chart B



B
C
10.0
V_{bb} = +4.2 v
R_A
1
10K
2
10K
2N3426
Q_1
555
7
1.0M
D_1
3
4
5
6
7
8
9
sync
15K
V_{bb}
Sensor
1
741
2.2k
2.2k
6
3
C
2N3426
Q_2
D
1.0M
15K
V_{bb}
74145
741
Sensor
2
2.2K
2.2K
D C B A
R_e
HEP 641
Q_3
R_2
R_1
7490
D_2
G
7432

Figure 8-a

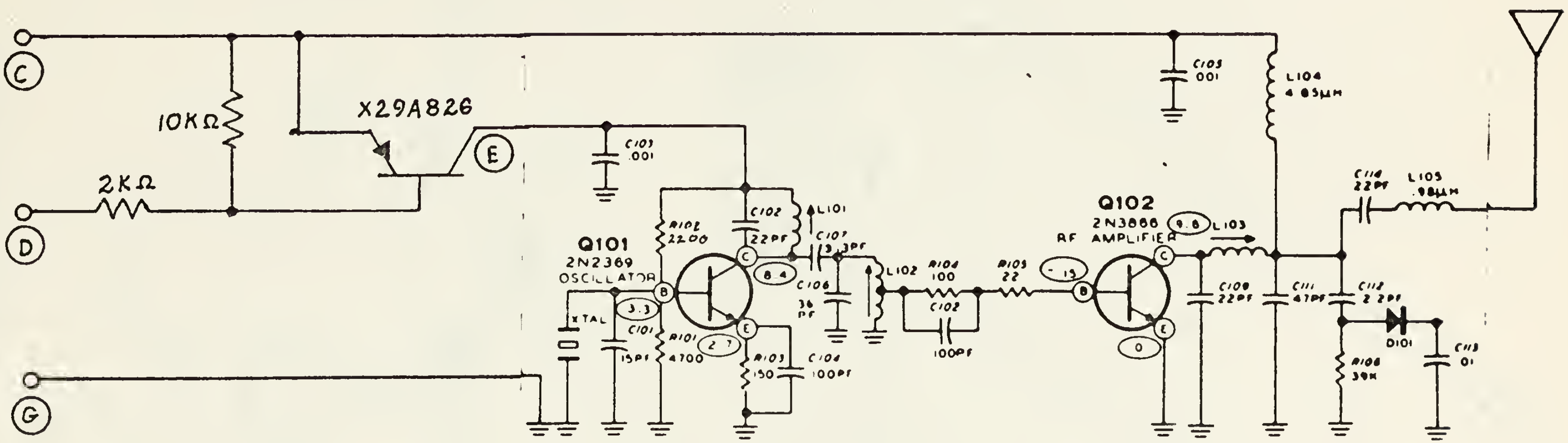


Figure 8-b. Transmitter

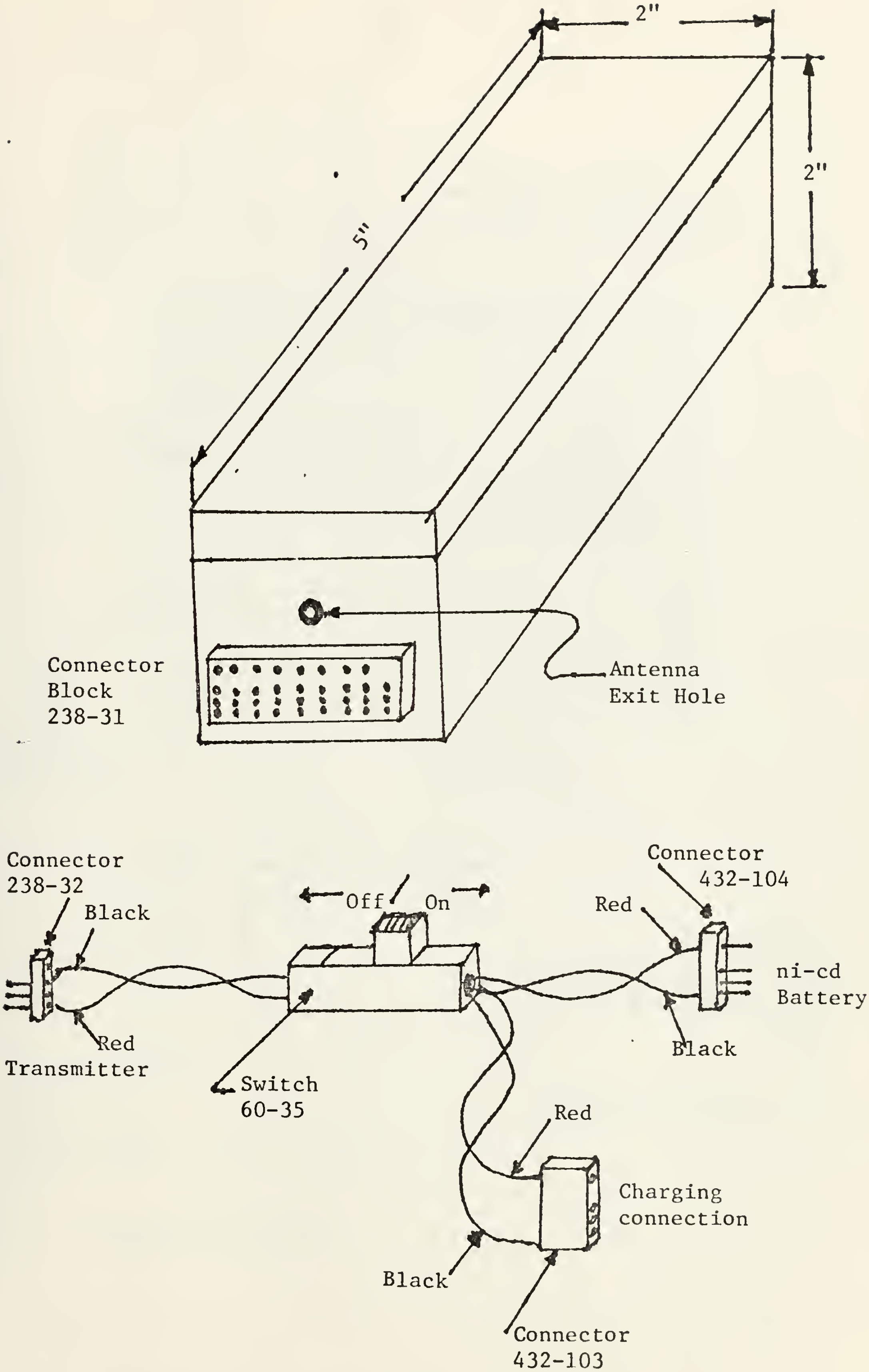


Figure 9. Transmitter Packaging

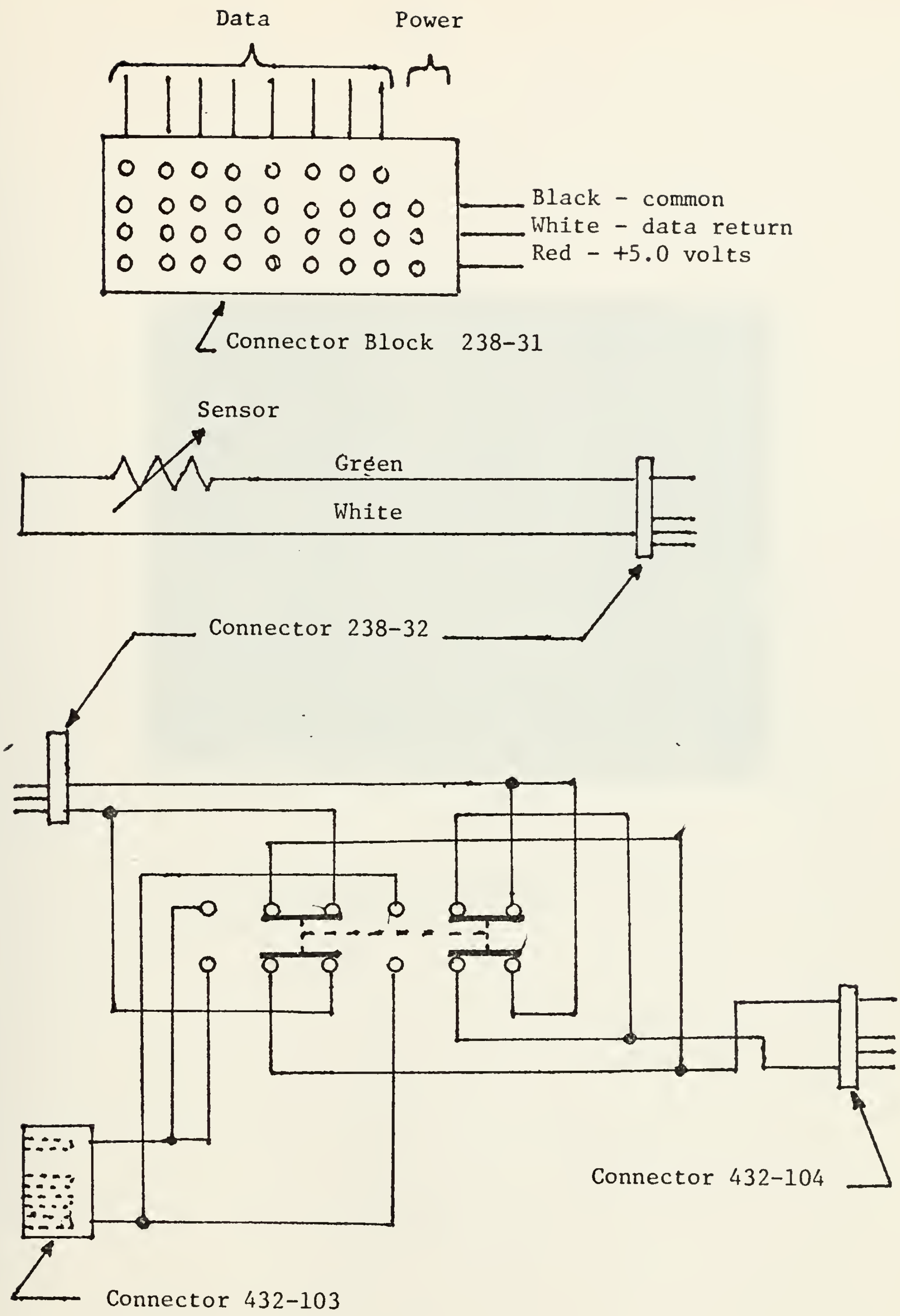


Figure 10. Connector and Switch Wiring

0.1 V/cm

1.0 msec/cm

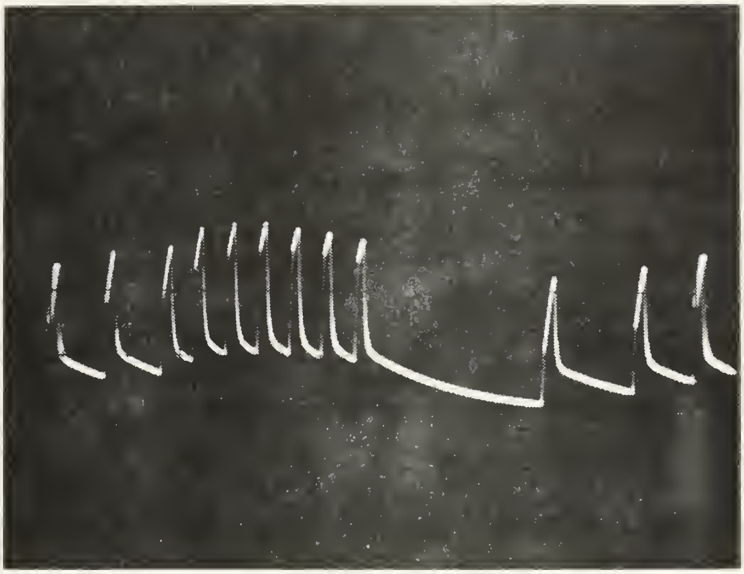


Figure 11. Receiver Output

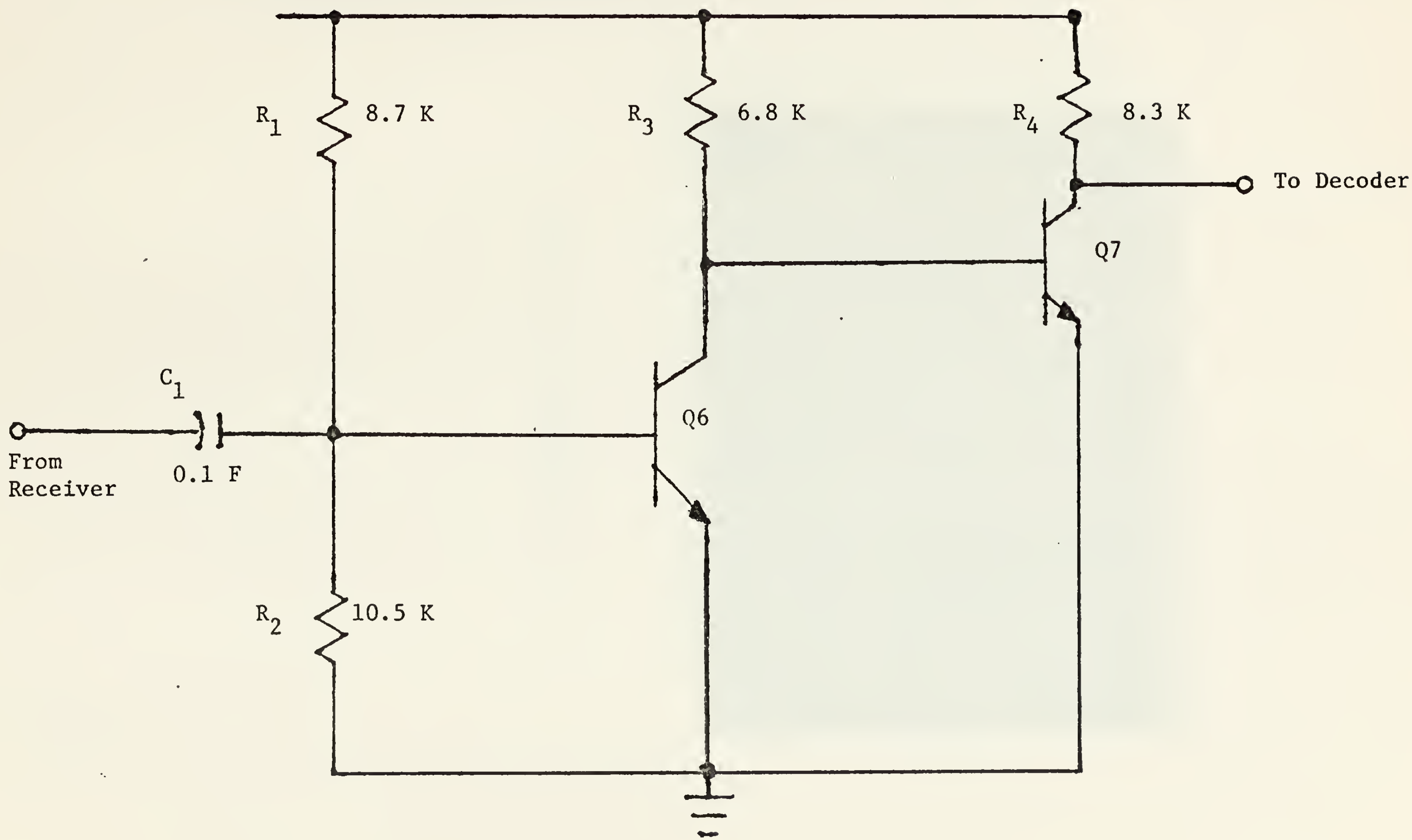


Figure 12. Decoder Interface Circuit

2.0 V/cm

1 msec/cm

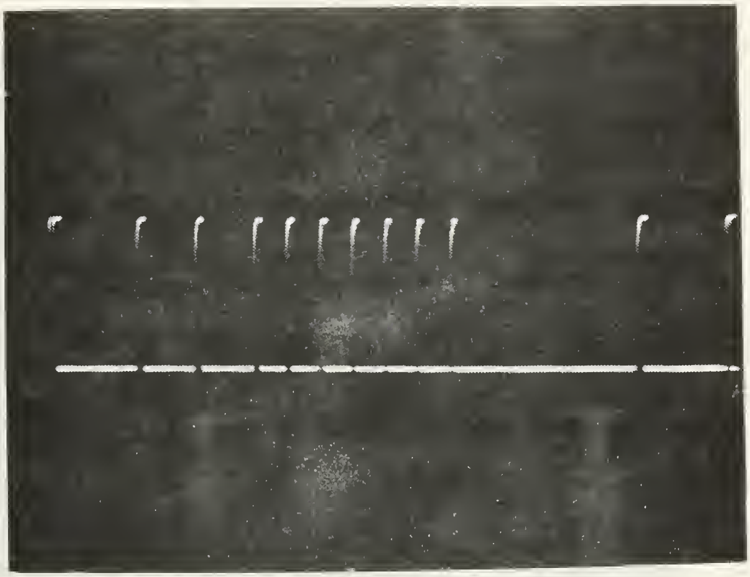


Figure 13. Decoder Input

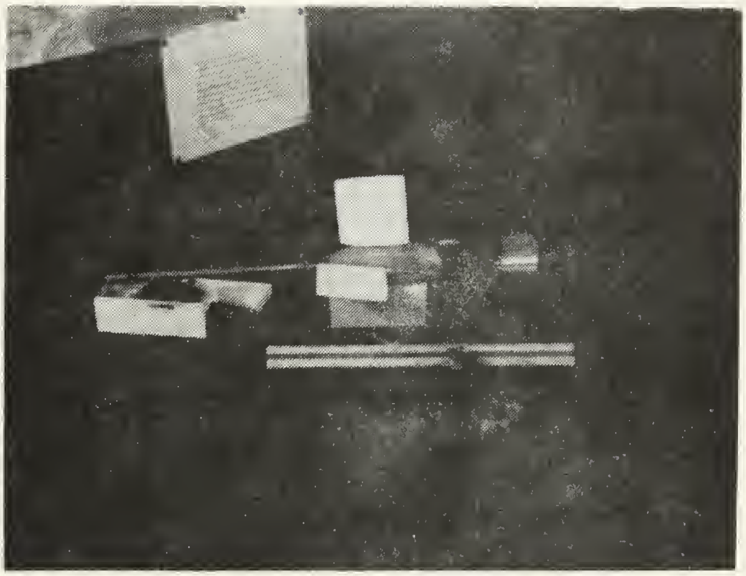


Figure 14. Airborne Package Components

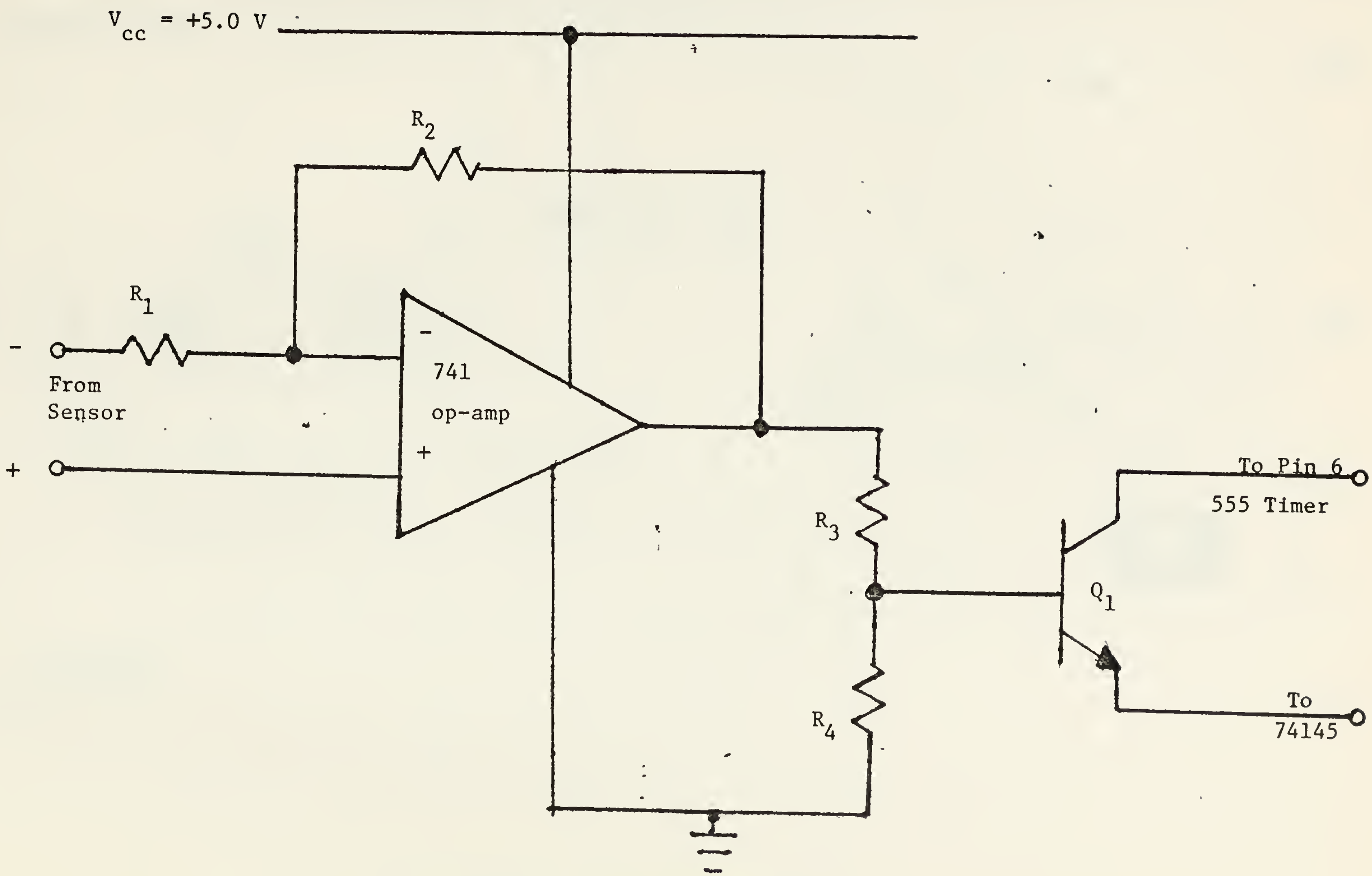


Figure 15. Encoder Modification

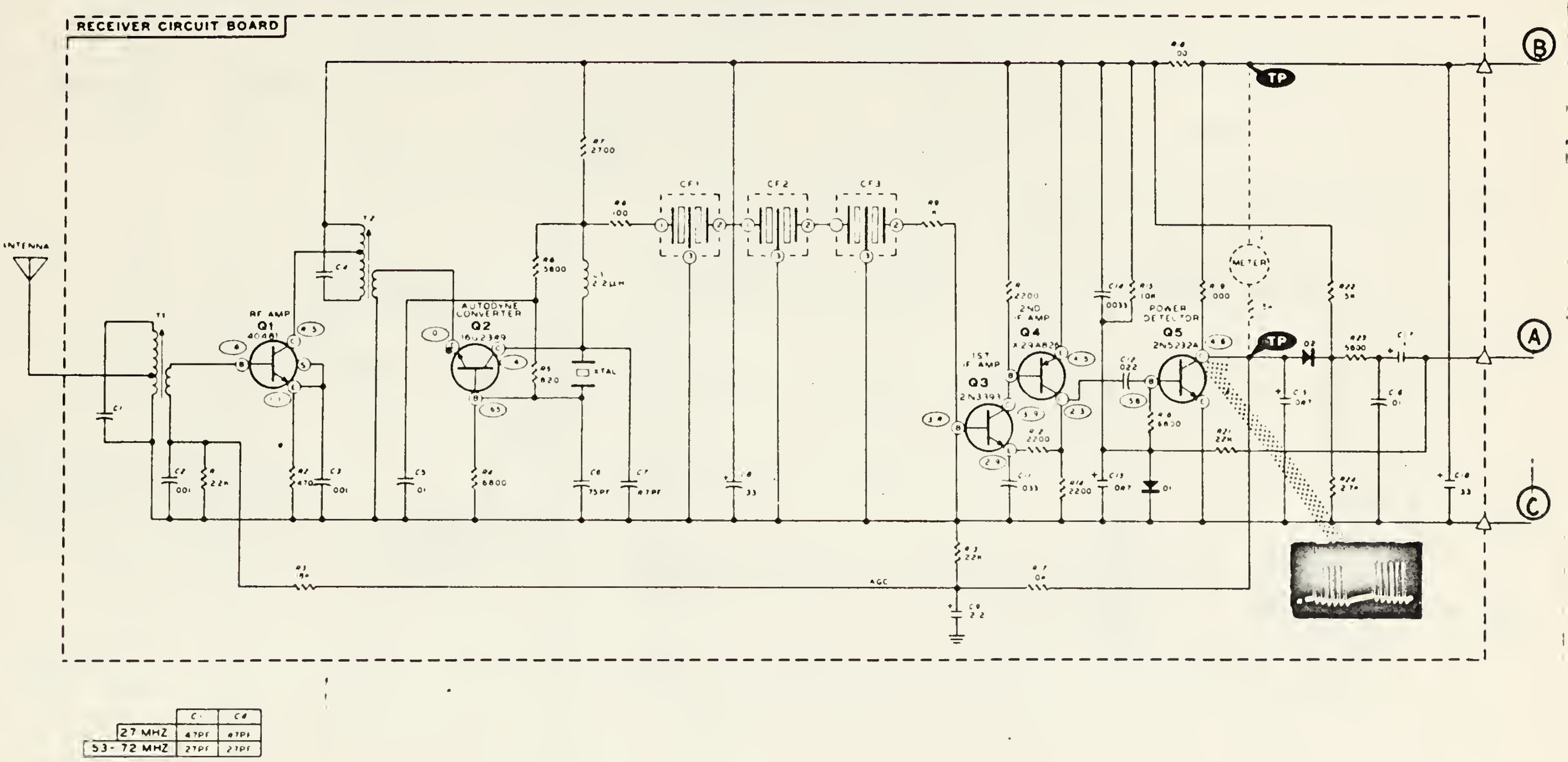


Figure 16-a. Receiver Circuit Board

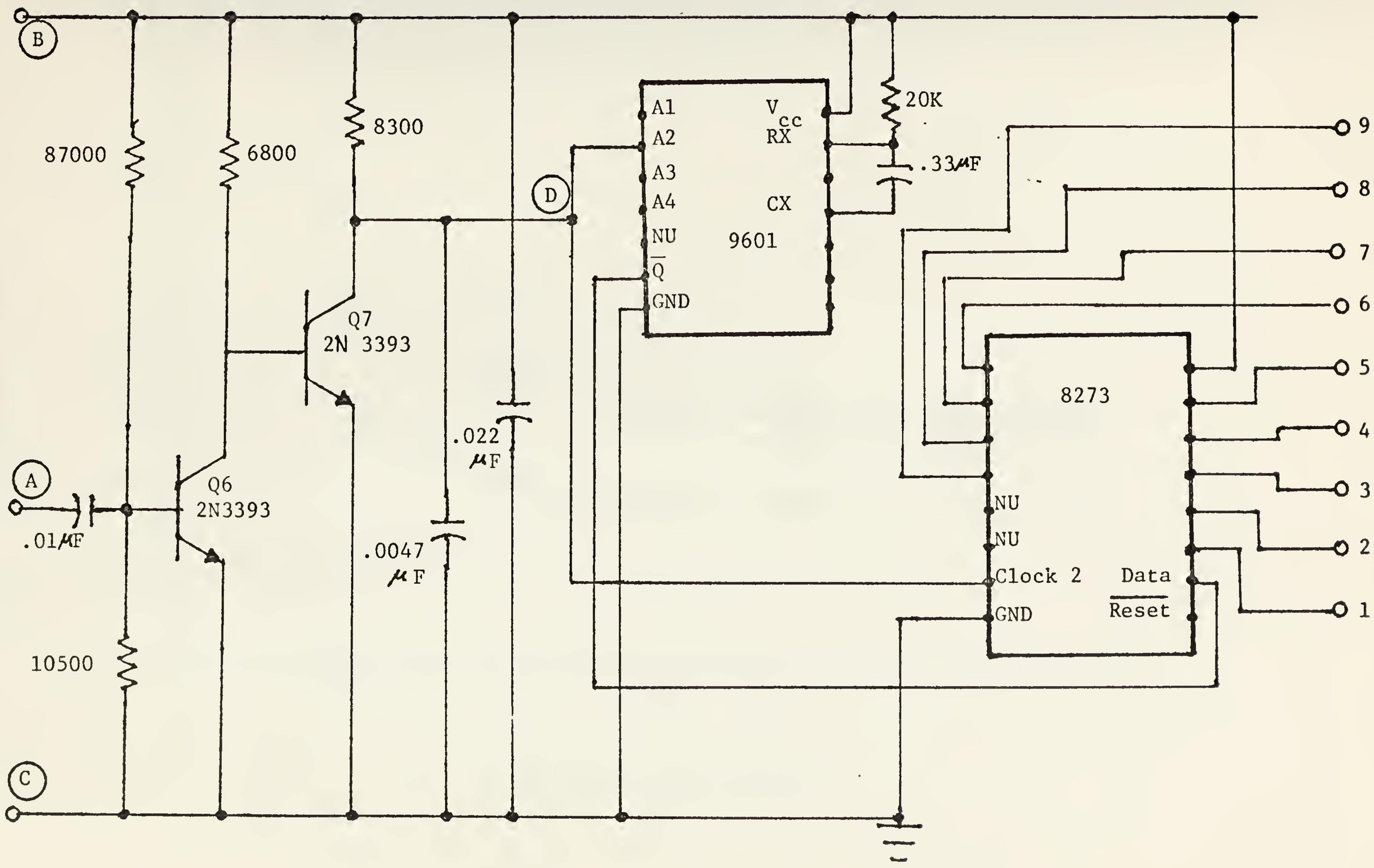
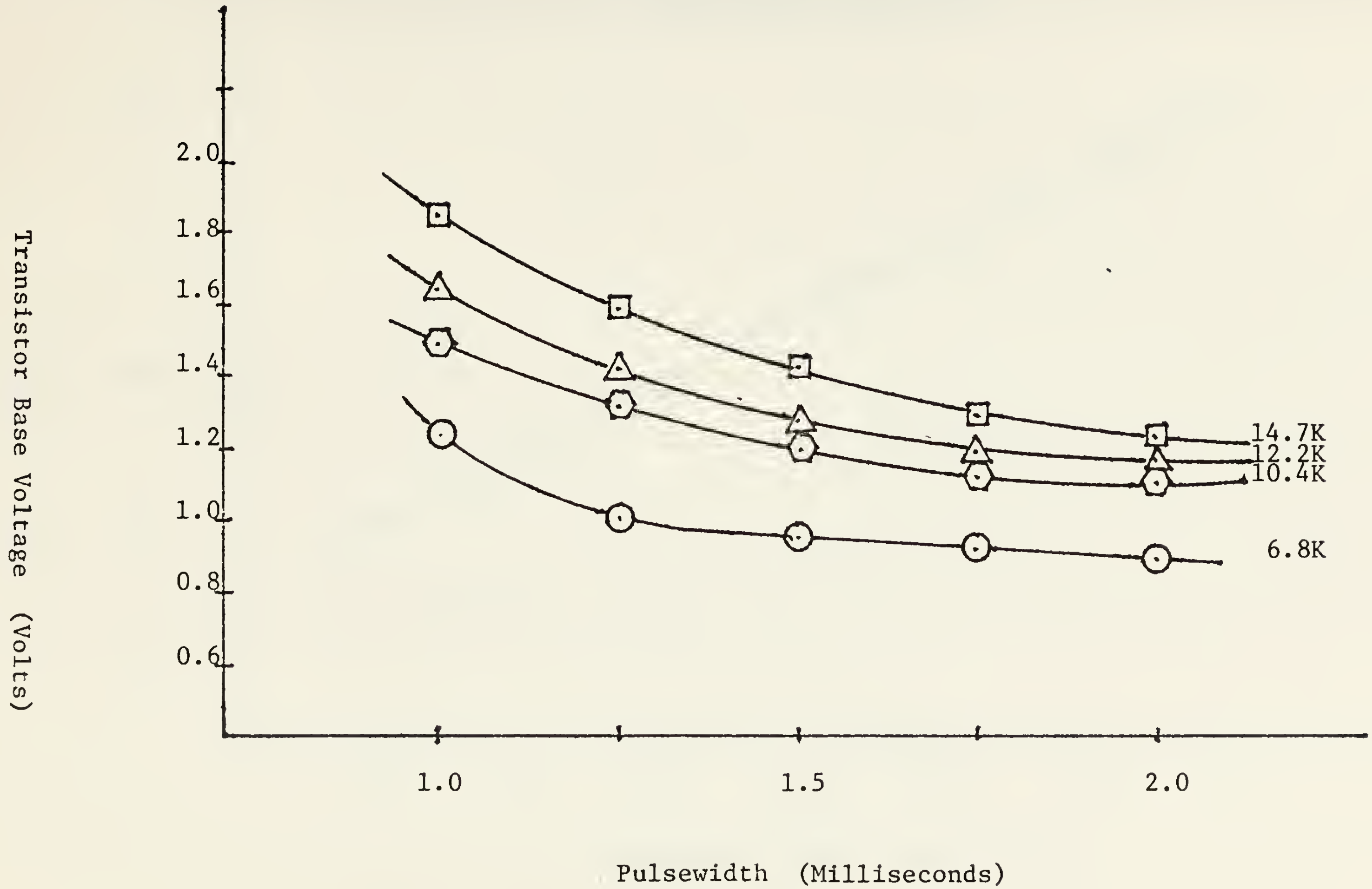
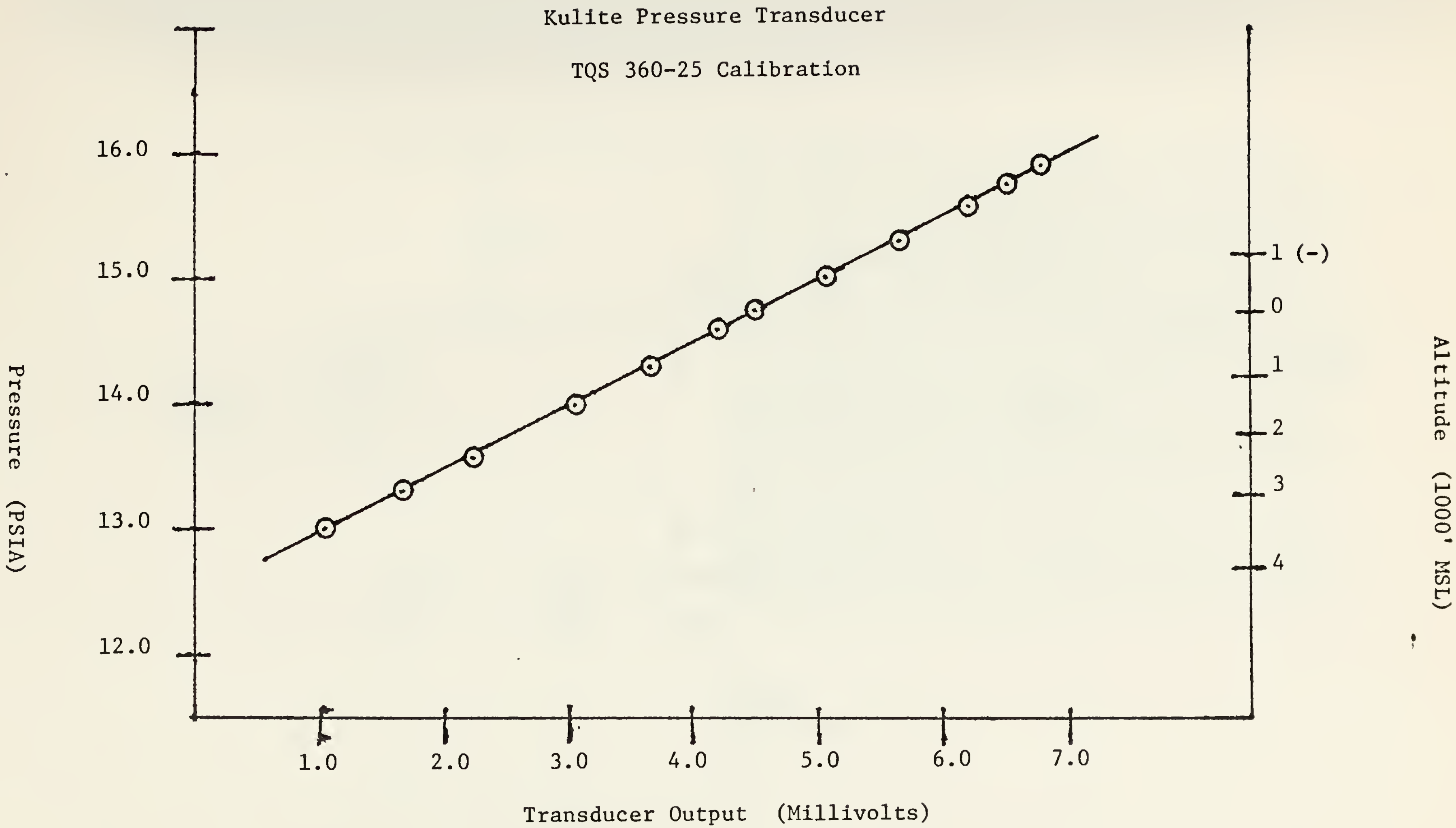


Figure 16-b. Decoder


Transistor Base Voltage (Volts)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
14.7K
12.2K
10.4K
6.8K
1.0
1.5
2.0
Pulsewidth (Milliseconds)

Graph 1


Kulite Pressure Transducer
TQS 360-25 Calibration
16.0
15.0
14.0
13.0
12.0
Pressure (PSIA)
1 (-)
0
1
2
3
4
Altitude (1000' MSL)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Transducer Output (Millivolts)

Graph 2

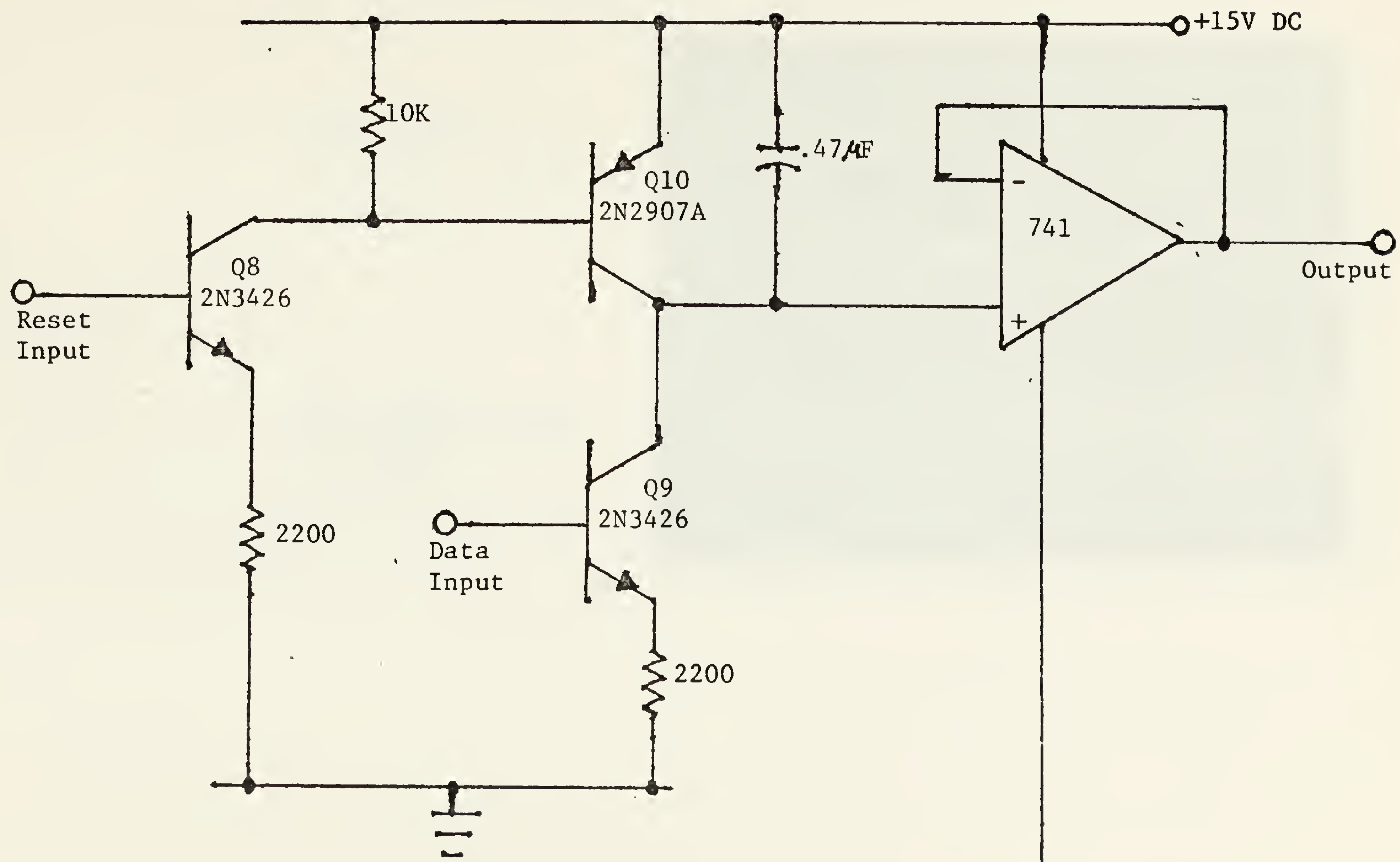


Figure 17. Output Signal Conditioner

a) Upper Trace:
Ch 1 Decoder Output
2.0 V/cm
0.5 msec/cm

b) Lower Trace:
Ch 2 Decoder Output
2.0 V/cm
0.5 msec/cm

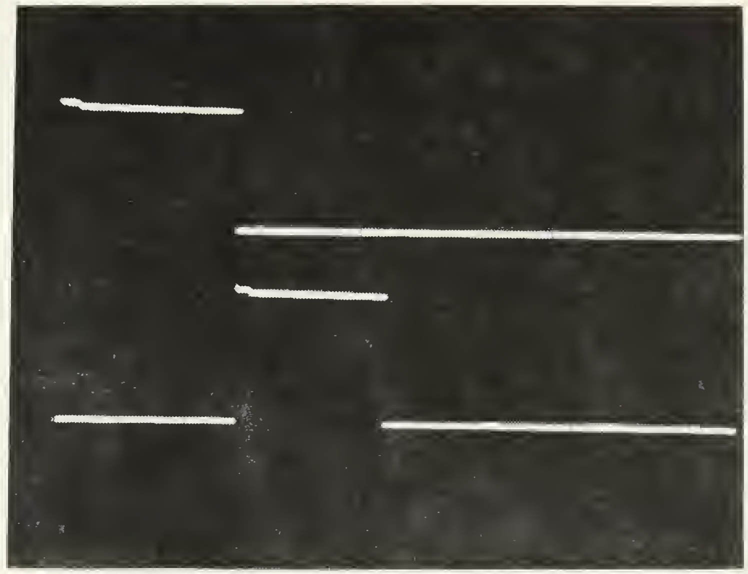


Figure 18. Decoder Waveforms

a) Upper Trace:
Ch 1 Decoder Output
2 V/cm
1.2 msec/cm

b) Lower Trace:
Ch 1 Conditioned Output (Inverted)
1.0 V/cm
1.2 msec/cm

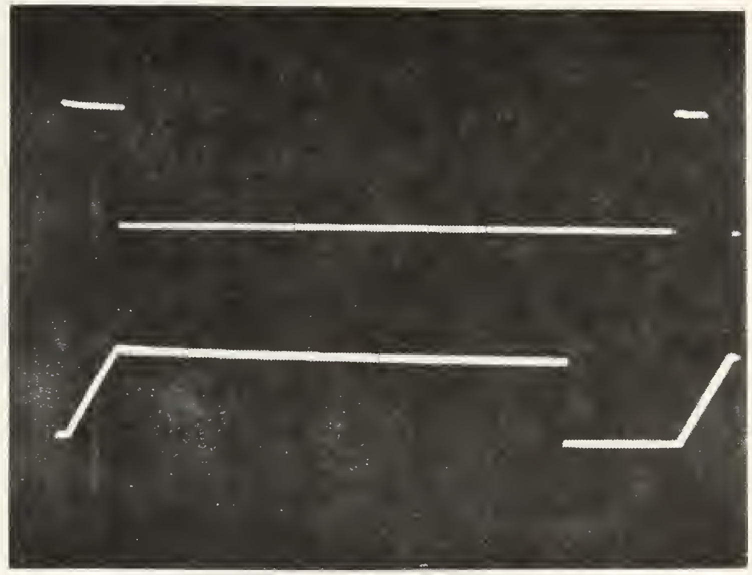


Figure 19. Output Waveforms

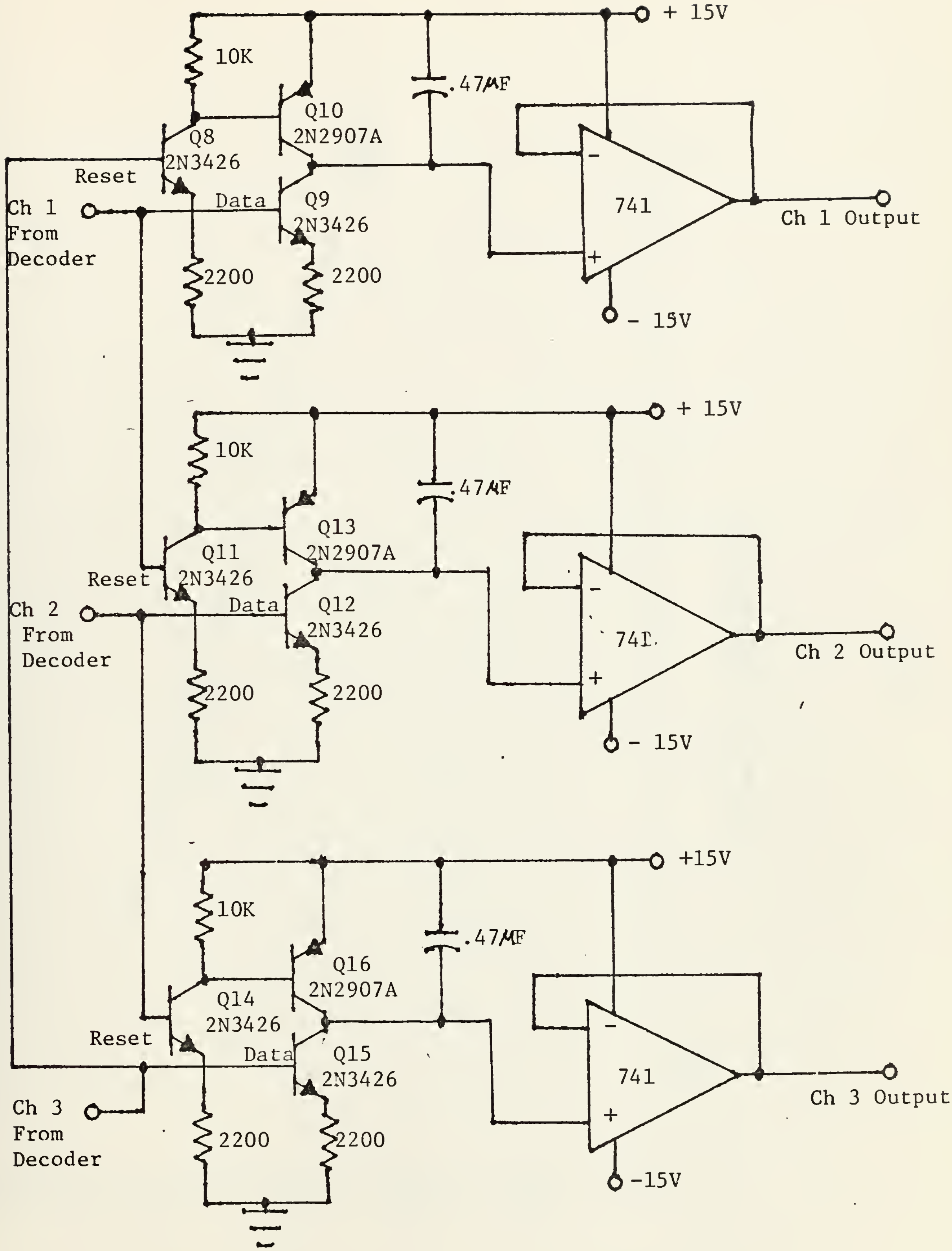
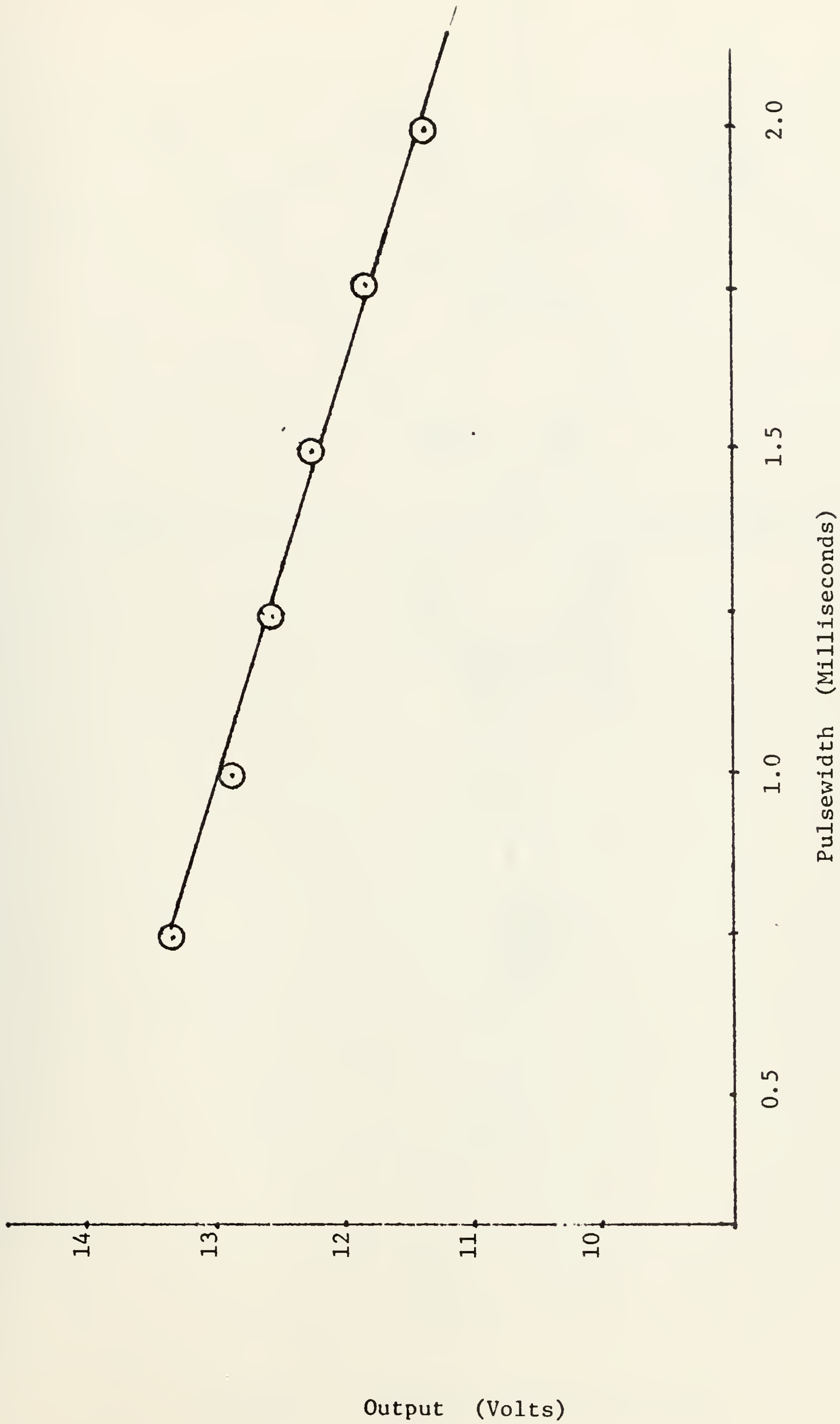


Figure 20. Output Signal Conditioning


14
13
12
11
10
0.5
1.0
1.5
2.0
Pulsewidth (Milliseconds)
Output (Volts)

Graph 3

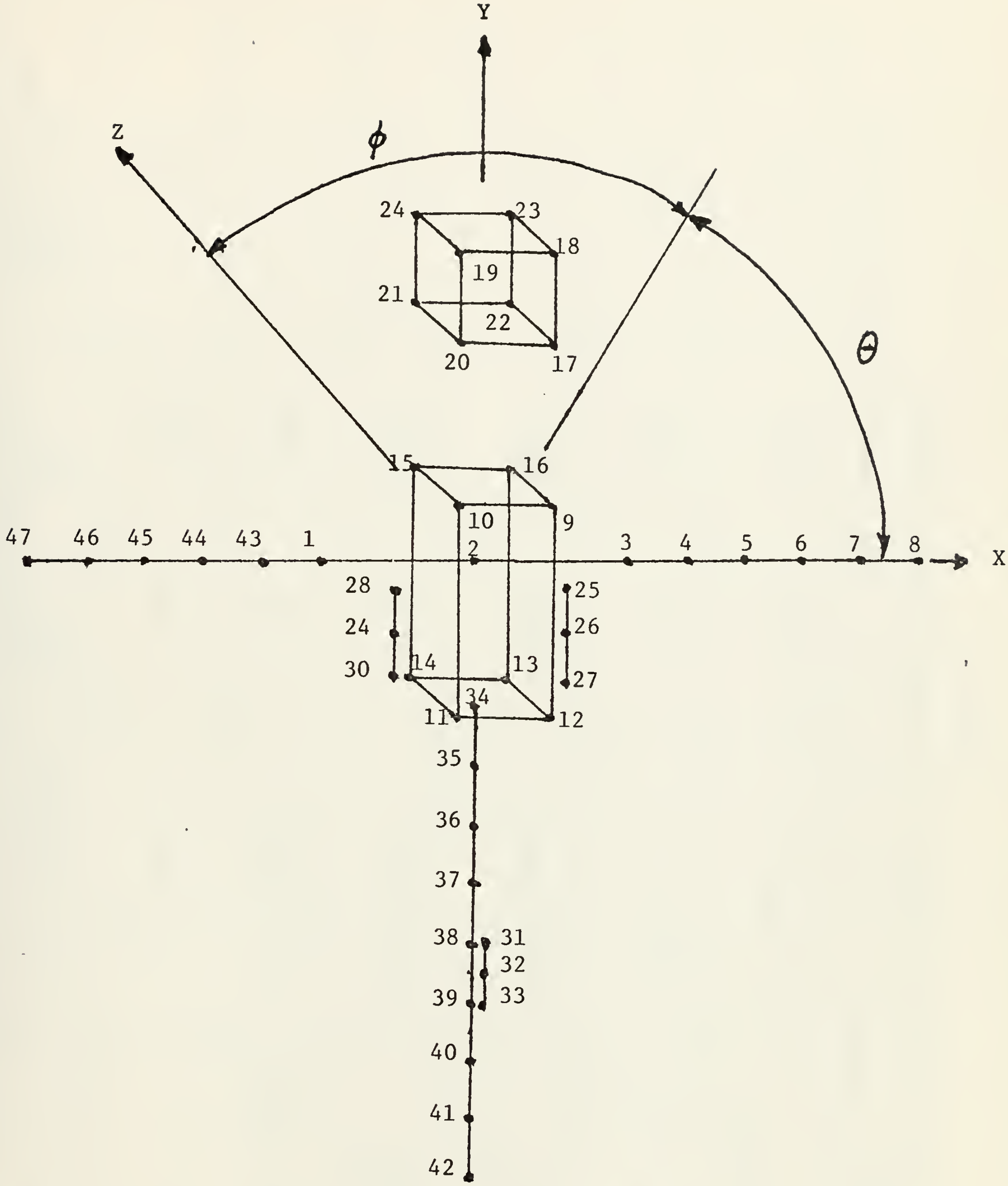


Figure 21. Computer Simulation Model

CONFIGURATION	INPUT IMPEDENCE	MAXIMUM POWER GAIN THETA	PHI	CURRENT 50 OHM LOAD X 10^{-6}
BASIC	11.95-J3803.0	0.1138	0.8261	4.23
BASIC WITH TOPHAT	17.01-J3768.0	0.1162	0.8253	4.97
FORE/AFT, NO TOPHAT FEED POINT 5	12.02-J379.0	0.1334	0.8275	11.20
FORE/AFT, NO TOPHAT FEED POINT 2	10.00-J3808.0	0.1280	0.8100	1.20
BASIC-FEED POINT 5	12.95-J379.0	0.1254	0.8328	35.50
DIPOLE-FORE/AFT MONOPOLE	33.00-J44.0	0.1264	0.8455	0.03

Basic-monopole transmitter antenna in starboard wing, monopole receive antenna in port wing.
Fore/aft-receive antenna changed to fuselage-located monopole.

Chart D

APPENDIX C

PRESSURE RANGE CALCULATIONS

In sizing the range to be covered by the altitude and airspeed transducers, the following procedures were used:

A. ASSUMPTIONS

1. The RPV envisioned for use with the MDTS will be operated at altitudes between sea level and 3000 feet.

2. The airspeeds anticipated will be up to 150 knots and therefore well within the limits of incompressible flow theory .

B. ALTITUDE CALCULATIONS

The table of absolute pressures was calculated to cover the anticipated barometric limits and altitude range.

Barometric Pressure (inches of mercury)	Altitude (feet) Pressure (PSIA)	
	Ø	3000
28.00	13.75	12.23
29.92	14.70	13.17
32.00	15.72	14.20

Table 1

The transducers required range was determined to be 12.0 to 16.0 PSIA.

C. AIRSPEED CALCULATIONS

From incompressible flow theory:

$$q = P_{total} - P_{static} = \frac{1}{2} \quad V^2$$

For the extreme case of 150 knots at sea level the dynamic pressure (q) to be measured is

$$P_{total} - P_{static} = \frac{V^2 \ P}{2} = \frac{(253)^2 \ \emptyset.00237}{2} = 0.53 \text{ PSIG}$$

APPENDIX D

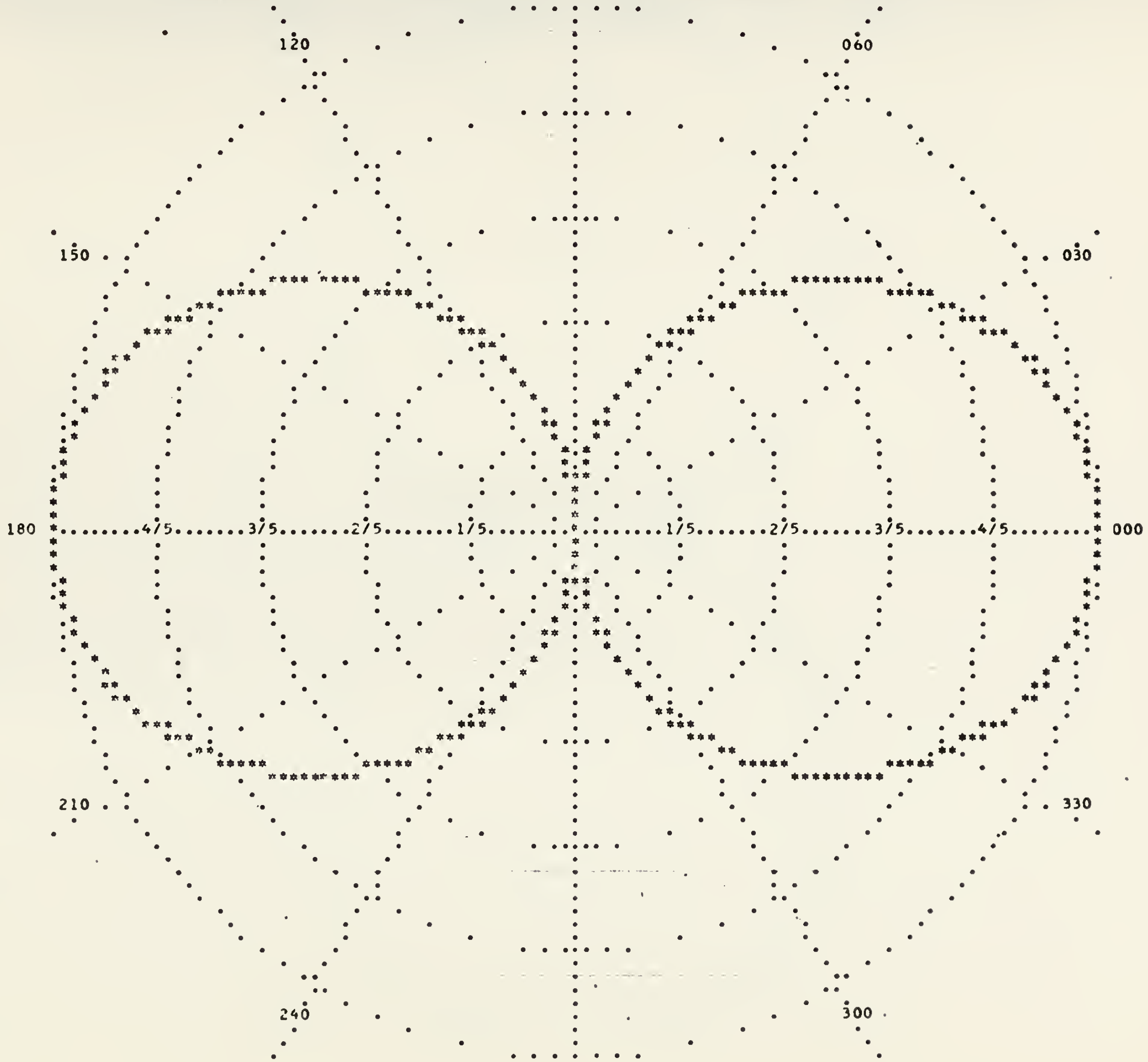
ANTENNA PATTERN COMPUTER PRINTOUTS

Appendix D includes computer printouts generated for the Dipole Transmitter Antenna configuration. The input data shown, when used the program described in Ref. 4 will produce the patterns shown. These patterns are presented only as a sample of the computer output available. The program allows selection and investigation of the results of varying many antenna configuration parameters.

```
*************************************
*                                   *
*      OHIO STATE UNIVERSITY        *
*    ANTENNA ANALYSIS PROGRAM       *
*      MODIFIED FOR USE AT          *
*   NAVAL POSTGRADUATE SCHOOL       *
*          17 JULY 1974             *
*                                   *
*************************************

C     THESIS/AIRCRAFT ANATENA SYSTEM
C
C      PHYSICAL LAYOUT AND INTERACTION
C

DATA CARDS

 1   WIRE(RADIUS=2.38M)
 2   GEOM(-0.230,0,0/0,0,0/.23,0,0/.38,0,0/.533,0,0/.69,0,0/.838,0,0/.99,0,0/
 3   .038,.076,-.05/-.038,.076,-.05/-.038,-.076,-.05/.038,-.076,-.05/
 4   .038,-.076,0/-.038,-.076,0/-.038,.076,0/.038,.076,0/.05,.152,-.05/
 5   .05,.254,-.05/-.05,.254,-.05/-.05,.152,-.05/-.05,.152,0/.05,.152,0/
 6   .05,.254,0/-.05,.254,0/.1,-.076,0/.1,-.1,0/.1,-.127,0/-.1,-.076,0/
 7   -.1,-.1,0/-.1,-.127,0/0,-.76,0/0,-.787,0/0,-.813,0/
 8   0,-.15,0/0,-.176,0/0,-.306,0/0,-.437,0/0,-.568,0/0,-.698,0/0,-.829,0/
 9   0,-.959,0/0,-1.09,0/-.38,0,0/-.533,0,0/-.69,0,0/-.833,0,0/-.99,0,0)
10   DESC(1-2/2-3/3-4/4-5/5-6/6-7/7-8/11-12/12-9/12-13/13-16/13-14/14-15/
11   15-10/10-11/11-14/10-9/9-16/16-15/20-17/17-18/17-22/22-23/22-21/21-20/
12   21-24/24-19/19-20/19-18/18-23/23-24/25-26/26-27/28-29/29-30/31-32/
13   32-33/34-35/35-36/36-37/37-38/38-39/39-40/40-41/41-42/1-43/43-44/44-45/
14   45-46/46-47)
15   FEED(2)
16   LOAD(2,190.,+90./38,50.,0.)
17   FREQ(56)
18   OUTPUT(FARF=45,50,65,80/STEP=5)
19   CHANGE

                    ******************************
                    *                            *
                    *        INPUT DATA          *
                    *                            *
                    ******************************

FREQUENCY (MHZ)                                  0.56000E 02
WIRE RADIUS (METERS)                             0.23800E-02
WIRE INSULATED (NO/YES)                               NO
EXTERIOR MEDIUM                                  FREE SPACE
GROUND PLANE (NO/YES)                                 NO
```

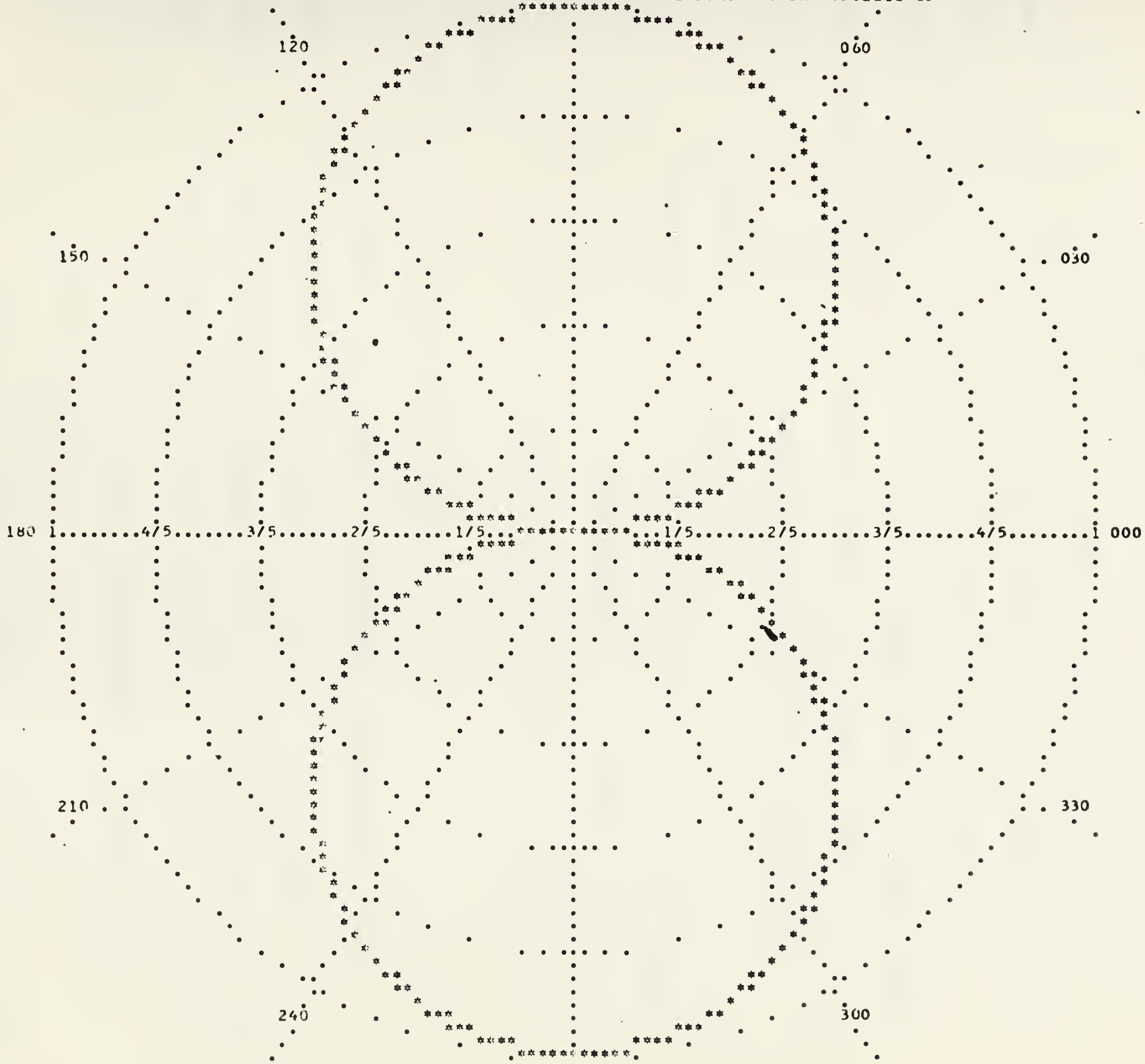
Dipole Antenna Configuration

THET ELECTRIC FIELD ANTENNA PATTERN FOR SPECIFIED PLANE.   NORMALIZING FACTOR= .71648E 00



Transmitter Dipole Antenna Pattern (Theta)

PHI ELECTRIC FIELD ANTENNA PATTERN FOR SPECIFIED PLANE. NORMALIZING FACTOR= .50221E-03



Transmitter Dipole Antenna Pattern (PHI)

APPENDIX E

OPERATIONAL CHECKLIST

The Miniature Digital Telemetry System makes extensive use of integrated circuits and transistors. Some parts of the system are also powered by batteries. The advanced nature of these categories of equipment requires some special consideration. Therefore the following check list was developed to assist in insuring satisfactory operation.

1. Integrated Circuits (I.C.)

Integrated Circuits are very sensitive to voltage and current fluctuations. Care should be exercised to insure that the maximum voltage limits of the I.C.s are not exceeded.

2. Nickel-Cadmium Batteries

NICAD batteries "have a memory", therefore they should be discharged to 4.6 volts prior to recharging. The batteries should then be charged for 16 hours at 50 milliamps prior to using again. The charge/discharge cycle is expected to provide 3 to 4 hours of continuous use between cycles.

3. Unused Sensor Terminals

For the system to operate properly, the unused sensor inputs must be shorted together individually. This is accomplished by connecting the green and white wires at each unused terminal point together.

4. Pressure Transducers

The altitude sensing system is measuring absolute pressure analogous to the pressure altitude system normally found in an aircraft instrument. Since the voltage output per PSIA of the transducer is fixed, it is only necessary to reset the altitude readout equipment to Ø prior to each day's flight. The airspeed transducer is a differential pressure transducer and therefore is independent of barometric pressure.

BIBLIOGRAPHY

1. Gadino, W., Miniature Digital Telemetry System Employing Cyclic Time Multiplexing Designed For Potentiometric Transducers, Engineers Thesis, Naval Postgraduate School, Monterey, 1974.

2. Signetics, Digital, Linear, MOS Integrated Circuits Data Book, 1974.

3. Signetics, Digital, Linear, MOS Intregrated Circuits Applications, 1974.

4. McCormick, J. W., "ASAP" Antenna-Scatterers Analysis Program Revised Edition October 1975, Masters Thesis, Naval Postgraduate School, Monterey, 1974. NPS-52AB74122

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